Enhanced Far Ultra-Violet Optical Properties of Physical Vapor Deposited Aluminum Mirrors Through Fluorination

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ABSTRACT

Astronomical instrumentation for measurements in the Far Ultraviolet (FUV, 90−200 nm) have historically considered aluminum (Al) thin film mirrors due to this material high reflectance over this wavelength range. However, the native aluminum oxide layer that forms on Al upon exposure to the atmosphere is strongly absorbing in this wavelength range, requiring that the films be protected with a dielectric that inhibits oxidation. Typically, magnesium fluoride (MgF_2) or lithium fluoride (LiF) coatings are used as protective layers, but each has shortcomings. For example, MgF_2 has an absorption cutoff at 115 nm that reduces performance below this wavelength, which is a critical part of the FUV spectrum for observational astrophysics. The use of LiF as a protection for Al provides a lower absorption cutoff at 100 nm, but it is hygroscopic and thus susceptible to degradation in humid conditions. Our team at GSFC has developed a new reactive Physical Vapor Deposition (rPVD) process that consists of a fluorination process with XeF_2 gas combined with our traditional PVD process. We have found that this new rPVD process produces Al+XeF_2+LiF (XeLiF) and Al+XeF_2+MgF_2 ($XeMgF_2$) mirror coatings with unprecedented reflectance. In addition, the rPVD process seems to produce much more environmentally stable coatings (when compared to the conventional process without the XeF_2 fluorination). We report on IR/Vis/UV reflectance of XeLiF and $XeMgF_2$ mirrors. The surface roughness as well as the FUV reflectance measured over a period of 8 months for a XeLiF sample with a relatively thin ($\simeq$ 30 nm) Al layer are also reported. We have also been investigating the compatibility of this rPVD coating process for potential efficiency enhancements of Si-based gratings. Since it is known that the XeF_2 vapor is a strong Si etchant, we are investigating if the native SiO_2 layer on Si is sufficient to protect the groove profile of E-beam-ruled Si gratings from degradation. Preliminary results indicate that the native SiO_2 layer is an effective barrier against etching of Si by XeF_2.

Keywords: Far Ultraviolet, FUV reflectance, aluminum, PVD, fluorination, XeF_2, Al, LiF, MgF_2

1. INTRODUCTION

The Habitable Worlds Observatory (HWO) is a large infrared/optical/ultraviolet space telescope mission concept that NASA is considering in response to the recommendation from the National Academies' Pathways to Discovery in Astronomy and Astrophysics for the 2020s survey.[1] This mission will have the scientific goal of searching for signatures of life on planets outside of our solar system in addition to perform transformational astrophysical observations in the far-ultraviolet (FUV) spectral range using the same platform. These scientific goals will require that the reflecting coatings on the telescope primary and secondary mirrors will have to cover a very broad spectra range from about 100 nm to 2.5 μm. In addition to having high reflectance performance, one key metric for these mirror coatings is that they must be resilient to the environment and be compatible with the high-contrast imaging system and other science instrumentation that will be part of the instruments suite for HWO. The 2020 Decadal report observed that the outstanding science discoveries that this mission is expected to accomplish will only be feasible if critical technologies reach Technology Readiness Level (TRL) 5

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or above within the next 4−5 years. Accordingly, improving optical coating technology has been identified as an "Essential Goal" in the technology needs that were identified in the two separate Science and Technology Definition Teams (STDT) studies that preceded the 2020 Decadal; namely the Large UV/Optical/IR (LUVOIR)[2] and the Habitable Exoplanet Imaging (HabEx) surveyor.[3]

To date, the mirror coatings of choice for use in the FUV have been either Al+MgF_2 or Al+LiF. The principal reason is that in the FUV spectral region above 100 nm, Al has the highest intrinsic reflectance of any known mirror coating. While the natural formation of Al_2O_3 degrades the reflectance below 200 nm, protective over-coatings of LiF or MgF_2 can extend the useful range down to their absorption cutoffs of 100 and 115 nm respectively. The performance of conventional Al+LiF significantly degrades when stored in humid environments as LiF is a hygroscopic material.[4] The degradation of LiF can be mitigated by keeping the mirrors in a dry environment (e.g., inert purge gas such as dry N_2) or stored under vacuum throughout integration and testing. However, the complexity associated with maintaining these risk-mitigation measures for an observatory such as HWO could be prohibitive. Therefore, a means of permanently protecting the LiF from moisture exposure is preferable. Some of the tested strategies to mitigate LiF degradation have been focused on either producing a more dense and compact protective layer, as hot-deposited fluorides are denser and therefore with less room for contaminants,[5] or by over-coating the mirror with an thin Atomic Layer Deposition (ALD) layer.[6] These two strategies of hot-deposition (eLiF) combined with a very thin ALD fluoride overcoat have been implemented and tested by Fleming *et al.* and the stability of the eLiF mirror coating has been significantly improved.[7] It is important to mention that although the effect of moisture in the optical properties of LiF films is well known, there is still limited knowledge about the physical mechanisms that ultimately drive the LiF degradation when exposed to moisture, with some exceptions such as the work of Lewis *et al.*[8]

Recent advances in deposition technologies have provided new possibilities for coatings that not only provide high reflectance, but improve ease of fabrication and handling as well as improved environmental stability. One of those studies reported earlier is a deposition process that uses a physical vapor deposition (PVD) process for both the Al and the metal-fluoride layer in combination with a fluorination agent (XeF_2 gas) after each layer deposition.[9] The process starts with a bare optically smooth substrate that is coated with Al in an ultra-high vacuum (UHV) chamber by the conventional PVD process. Then, the bare Al mirror is immediately exposed to a reactive XeF_2 gas before and after the application of the flash PVD evaporated LiF or MgF_2 layers.

In this paper, we are reporting further experimentation and optimization of the reactive physical vapor deposition (rPVD) process that was reported in that earlier work.[9] This coating process offers protection of Al coatings with a more stable and transparent LiF protection layer, along with state-of-the-art reflectance that far exceeds what is possible with the conventional PVD process.[10] This paper will also report on the implementation of the rPVD process for the deposition of Al protected with a MgF_2 overcoat (which also exceeds reflectance performance when compared to the conventional process) as well as to study the etching effect of XeF_2 on bare and Al-coated Si wafers. The paper is organized as follows: The experimental details are discussed in Section 2, while Section 3 reports on the characterizations obtained with both types of Al+XeF_2+LiF (XeLiF) and Al+XeF_2+MgF_2 ($XeMgF_2$) samples that include spectral reflectance (Sec. 3.1). Section 3.2 reports on experiments performed to demonstrate the compatibility of the XeF_2 fluorination process with Si-based gratings.[11] This section also include experimental characterizations on these samples with a Scanning Electron Microscope (SEM). Section 3.3 reports on X-Ray Photo-electron Spectroscopy (XPS) experiments on Al samples only treated with the XeF_2 fluorination gas. Section 3.4 will report on an aging study performed on a XeLiF sample with a thin ($\simeq$ 30 nm) Al layer that included monitoring the stability of the sample under varying temperature and relative humidity conditions and by measuring its FUV reflectance over time. Section 3.5 will report Atomic Force Microscopic (AFM) on the same XeLiF sample discussed in Section 3.4. Section 4 provides some concluding remarks.

2. EXPERIMENTAL DETAILS

The rPVD coating technology along with the chamber in which it has been carried out have been described before.[12] The process starts by placing the substrates inside a 0.5-m diameter stainless-steel bell-jar deposition chamber. The chamber is pumped with a cryo-cooled pump system with the fore vacuum provided by a rough mechanical pump. The base pressure of the chamber is typically 1.9×10^{-8} Torr. The Al deposition is done

via evaporation from tungsten coils. The average Al deposition rates is around $150-200$ Å per second. The metal-fluoride dielectric depositions are carried out with a molybdenum bowl with a deposition rate ranging from 40 Å/s to about 70 Å/s. Film thicknesses were measured *in-situ* with a quartz-crystal monitor (QCM) that had been previously calibrated through stylus profilometry. A key aspect is the fact that the bare Al mirror is immediately exposed to the reactive XeF_2 gas. The quick exposure *in-situ* of bare Al to XeF_2 grants a thin ($\approx$2.5−3.2 nm) protective layer of AlF_3. Once the metal-fluoride overcoat is applied and the mirror stack is completed, it is exposed again to a high partial pressure of XeF_2 for a few seconds. The process described here is similar to the conventional PVD where all the steps are carried out at ambient temperature. The only difference is the use of the XeF_2 gas after each of the Al and metal-fluoride PVD depositions. The samples were prepared on a variety of substrates including Ultra-low Expansion glass (ULE), Zerodur, soda-lime glass, and Si wafers.

After the mirror coating fabrication, spectral reflectance in the 90−180nm range was performed with a McPherson Vacuum Ultraviolet (VUV) 225 spectrophotometer. A Perkin-Elmer monochromator (Lambda 950 model) for coverage in the 200−2500 nm range is used for collecting reflectance data in the near-UV/Visible/Near-Infrared spectral regions. The estimated absolute reflectance error with either instrument is estimated to be $\pm$ 1%. Atomic force microscopy (AFM) was used to study the surface roughness, and measurements were performed using a Park Systems (NX20 model) instrument in tapping mode with 256 samples/line. The topography was acquired in one field of 1×1 μm^2. Surface analysis that includes stoichiometry and contamination characterization was performed with a X-Ray Photo-electron Spectrometer (XPS) with a monochromatic Al kα source and a hemispherical analyzer. Finally, the samples prepared on the Si substrate were analyzed with a Scanning Electron Microscope (SEM) to study surface effects that may have been caused by the XeF_2 process on the Si-based substrates.

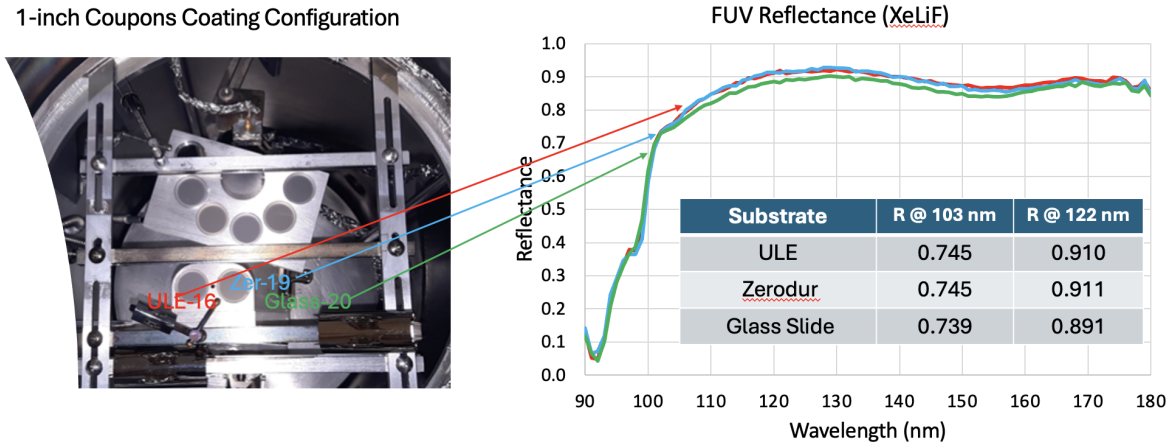


Figure 1: Left side: Relative position of these samples inside the 0.5-meter coating chamber during the rPVD deposition. Right side: FUV reflectance of XeLiF samples prepared on ULE, Zerodur, and soda-lime glass substrates.

3. RESULTS

3.1 Spectral Reflectance

The right side of Figured 1 shows the FUV reflectance performance of various XeLiF mirror coupons fabricated on ULE, Zerodur, and soda-lime substrates with the rPVD process described above. The thickness of the Al layer is $\approx$ 65 nm. The AlF_3 thickness provided by the XeF_2 fluorination is around 2.5 nm, while the LiF thickness is $\approx$ 15 nm, where the latter is chosen in order to provide the higher reflectance possible at the Hydrogen Lyman-α line (121.6 nm), while keeping high reflectance down to the Lyman-β wavelength of 102.6 nm. These two wavelengths are important reference wavelengths in cosmology to measure absorption produced by a smoothly fluctuating intergalactic medium and to study galaxy evolution.[13] The reflectance value at 121.6 nm of $\approx$ 0.91 compares very favorably with results reported earlier in Ref. [9], where its is reported $R \approx 0.90$ at the same wavelength for the rPVD process of the coating combination of $Al/AlF_3/LiF$. These results indicate a quite reproducible

process in providing the highest ever reflectance in the literature.[10,12,14,15] The very noteworthy difference is that most of these earlier works used a high substrate temperature process, with the exception in Ref. [12] where a room-temperature E-beam generated plasma in a SF_6/Ar gas mixture was used to passivate and protect the Al with an AlF_3 overcoat. A second important consideration is that samples prepared with the XeF_2 fluorination exhibit a remarkable stability when compared to samples prepared without the fluorination process.[9] The left side of Fig. 1 shows the configuration of how each of the coupons were mounted inside the coating chamber. The optimum uniformity area in the chamber is around 4×4 inches^2. The samples labeled ULE-16 and Zer-19 show excellent uniformity as illustrated by the nearly identical reflectance for these two samples at 103 nm and 122 nm. The data for the 2×2 inch^2 witness sample (made on soda-lime glass) shows some slight reduction in reflectance at these two wavelength values. This is partially accounted for by the fact that this sample was placed nearly the edge of the 4×4 inches^2 optimum area where there is good coating uniformity. Although as it is mentioned later, the higher RMS roughness of the glass slides (when compared to the ULE or Zerodur) may have played a role in the lower FUV reflectance of samples grown on this type of substrate. A phenomenological description of

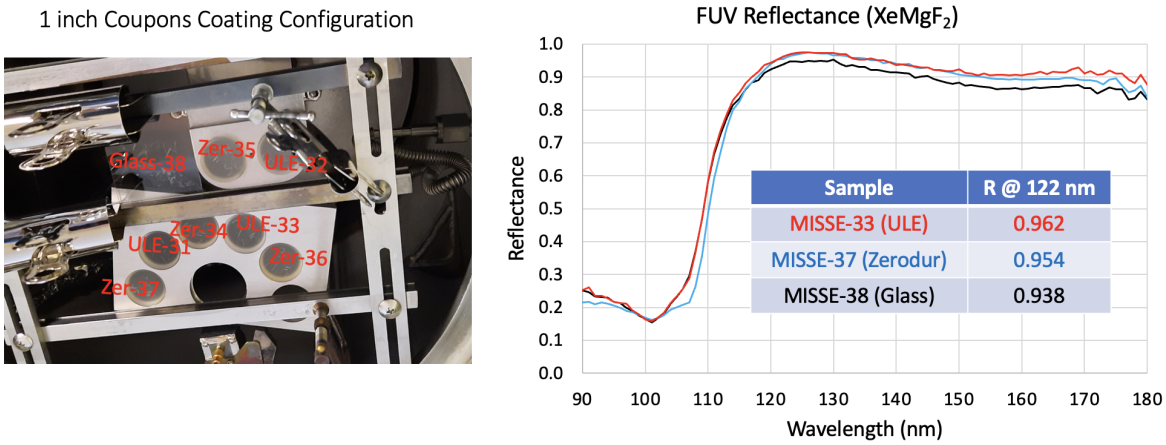


Figure 2: Left side: Relative position of these samples inside the 0.5-meter coating chamber during the rPVD deposition. Right side: FUV reflectance of $XeMgF_2$ samples prepared on ULE, Zerodur, and glass slide substrates.

the effects of the XeF_2 and the flash evaporation of LiF in the mirror quality was provided in Ref. [9]. The key conclusion is that the exposure of Al to XeF_2 immediately after its deposition grants a thin but highly protective AlF_3 layer that prevents Al from reacting with the residual gases inside the chamber, particularly with water vapor. Secondly, the exposure of bare Al to XeF_2 saturates the Al surface with fluorine, resulting in a thin barrier layer of AlF_3 that prevents a possible reaction between Al and Li and F. And as described in Ref. [9], what happens at the Al-LiF interface affects the mirror performance.

The right panel of Fig. 2 displays the FUV reflectance performance of several $XeMgF_2$ witness coupons (made on ULE, Zerodur, and glass substrates) that were prepared with the XeF_2 fluorination process described above. The thickness of the Al layer is 65 nm (similar as in the XeLiF samples), while the combined AlF_3 and MgF_2 film thickness is 24 nm. The left side in Fig. 2 shows the relative location for each of the substrate during the deposition inside the coating chamber. The average reflectance (among the ULE and Zerodur substrates) is $\sim 96\%$ at 122 nm. The value for the glass slide is around 2% lower at the same wavelength. The variation seen in the glass substrate data (when compared to the ULE and Zerodur samples) is partially attributed to the fact that there is some slight non-uniformity of the MgF_2 layer thickness given that the glass slide was placed near the edge of the optimum location for good coating uniformity. Additionally, the ULE and Zerodur substrates have a better (< 5 Å) RMS surface roughness when compared to the soda-lime glass slides RMS roughness (< 7 Å). This larger surface roughness could be a source of increased surface light scattering that will produce a reduced specular reflectance. The average reflectance value for the ULE and Zerodur data is a substantial improvement (over 5%) when compared to the results reported earlier with the 3-step hot process.[10] The key difference in the results shown in Fig. 2 is that the deposition was done at ambient temperature. There was another report

of reflectance above 0.90−0.91 at 122 nm for Al protected with MgF_2.[16] In this case, the substrate was also maintained at ambient temperature but an optimization of the PVD parameters was performed with a high deposition rate (over 96 Å/s for the MgF_2 layer. The results shown in Fig. 2 represent the highest ever reported reflectance of Al protected with any of the three more regularly used metal-fluoride coatings (MgF_2, LiF, or AlF_3).

It is worth to point two more recent reports of protected Al which provides reflectance over 95% at Lyman-α. One of those used a protection layer called cryolite or trisodium hexafluoroaluminate (AlF_6Na_3).[17] The highest reflectance reported with this material in this work is around 96% at 122nm.[18] However, the cutoff wavelength for this version of cryolite does not go as low as any of the other metal-fluorides ($\simeq$ 120 nm) and it is also highly hygroscopic. The second report used a variant of the cryolite overcoat, where the Na atom is replaced with Li for a chemical composition of AlF_6Li_3. In this case, the maximum reflectance from samples protected with this second version of cryolite and prepared with the rPVD process is about 99% at the Lyman-α wavelength.[19] The cutoff wavelength for this material is similar to that of MgF_2 ($\simeq$ 115 nm). However, initial aging studies showed some degradation in the FUV reflectance (a drop of $\sim$ 6% at 122 nm) when samples were kept in ambient laboratory conditions (25°C and 50−60% relative humidity) for a period of 23 weeks.[19] Even though this degradation was still half of conventional Al+LiF, these results show this version of cryolite is not as stable as the aging study performed earlier on XeLiF samples[9] or the more recent studies on the XeLiF samples reported in Ref. [22].

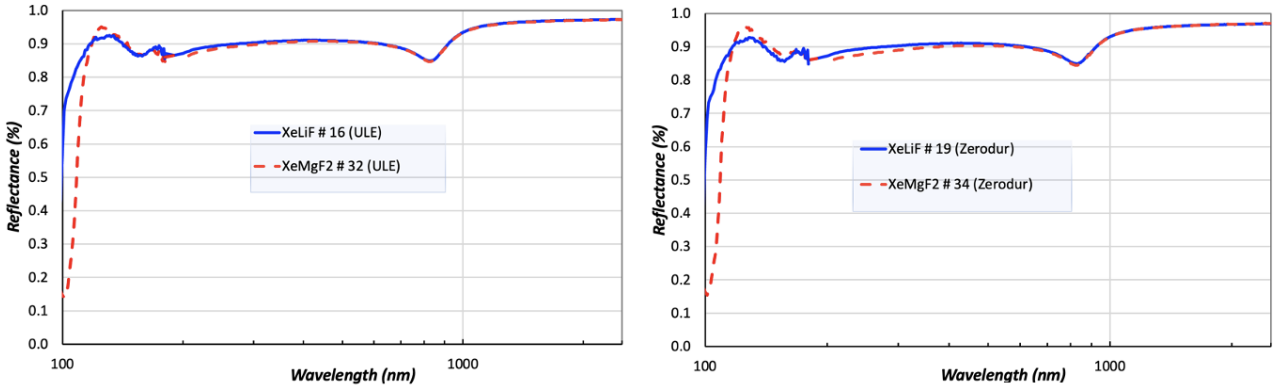


Figure 3: Broad-band reflectance performance of XeLiF and $XeMgF_2$ coatings on ULE and Zerodur substrates over the FUV/UV/Vis/NIR spectral ranges.

Figure 3 displays the broad-band reflectance performance (with wavelength in a logarithmic scale) of XeLiF and $XeMgF_2$ samples over the FUV/UV/Vis/NIR spectral ranges. The left side of this figure shows data on ULE substrates, while the right panel displays data collected on Zerodur substrates. The first observation is that results are nearly identical (for each XeLiF and MgF_2) and regardless substrate. Secondly, both types of coatings perform nearly the same for wavelengths longer than 500 nm. The major difference is shown in the FUV spectral range where the reflectance for the XeLiF samples stays over 65% down to 100 nm. Meanwhile, the Al mirror protected with MgF_2 shows a reflectance that is slightly lower (by about 1−2% in the UV and part of the visible spectral ranges.

3.2 Effect of XeF_2 Passivation on Silicon

Single crystal Si diffraction gratings are an important innovation for far-UV spectroscopy as they can be etched to provide atomically smooth blazed profiles using electron beam lithography.[11] However and unlike ULE or Zerodur glass substrates, which are stable in the presence of XeF_2 vapor, it has been well documented that Si can easily be etched by fluorine containing gases.[20,21] Given that the efficiency of E-beam produced gratings made from Si substrates would greatly benefit from the high reflectance performance of the rPVD coating process, we set out to determine the compatibility of this coating technology with Si-based substrates. To this extent, several test mirrors on Si wafers were fabricated and looked at using first Scanning Electron Microscopic (SEM). The end goal is to determine if the native SiO_2 that will readily form on freshly cleaved Si would be sufficient to protect any Si substrates or gratings from XeF_2 etching.

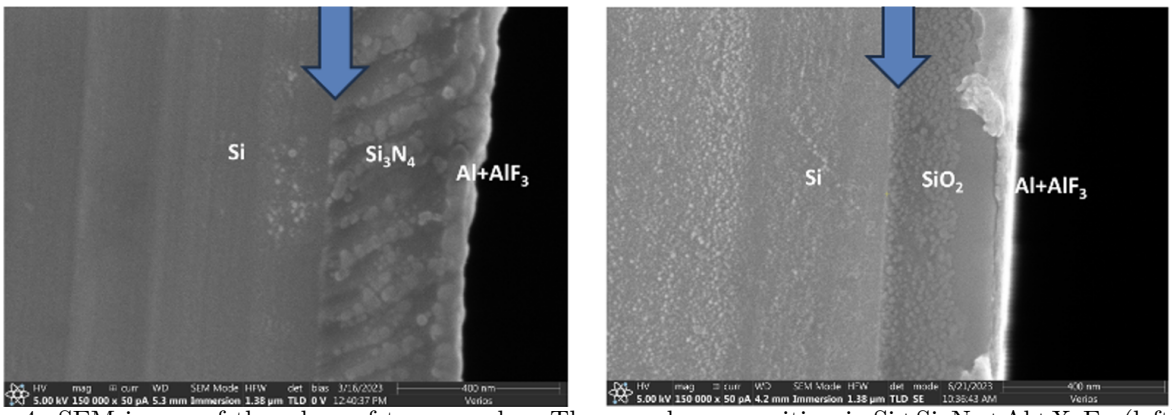


Figure 4: SEM image of the edges of two samples. The sample composition is Si+Si_3N_4+Al+XeF_2 (left) and Si+SiO_2+Al+XeF_2 (right). The observed edge of the right sample was freshly cleaved within a few minutes before being in vacuum to minimize the growth of the native oxide on the sides of the Si edge.

The first test used a Si_3N_4-coated Si substrate. This Si_3N_4 coating choice was made to use spectroscopic ellipsometry to evaluate possible change in the Si (or Si_3N_4 layer) due to XeF_2 etching, since Si_3N_4 has a particular ellipsometry fingerprint that allows for the detection of tiny variations on the optical properties or thicknesses of this layer or the Si wafer. Figure 4 on the left shows the edge of a Si_3N_4 on a Si wafer with approximately 40 nm Al thermally evaporated on top and then exposed to XeF_2 to passivate the Al surface. The layer divisions are all visibly well-defined aside from the AlF_3, resulting from the reaction of the Al with the XeF_2. This is because the AlF_3 layer is only $\approx 2-3$ nm thick. It is somehow visible as the bright layer on the surface of the Al. Any unusual marks on the image are attributed to damaging from handling and no evidence of undercutting or etching is seen. No shadowing at the Si/Si_3N_4 interface is observed, and no features on the Si indicating etching or undercutting from the XeF_2 exposure is observed to have taken place.

We also performed a second experiment with a Si wafer coated with same 40 nm of Al and then passivated with XeF_2. The sides of this sample were freshly cleaved within a few minutes before being placed in vacuum to minimize the growth of the native oxide on the sides of the freshly cleaved Si edge (Fig 4, right). Again, no shadowing or undercutting were seen at the Si/SiO_2 boundary and on the cleaved Si surface. This supports the conclusion that the small amount of growth of the native oxide that forms within minutes on the Si surface will be sufficient to protect the substrate from the XeF_2 etching.

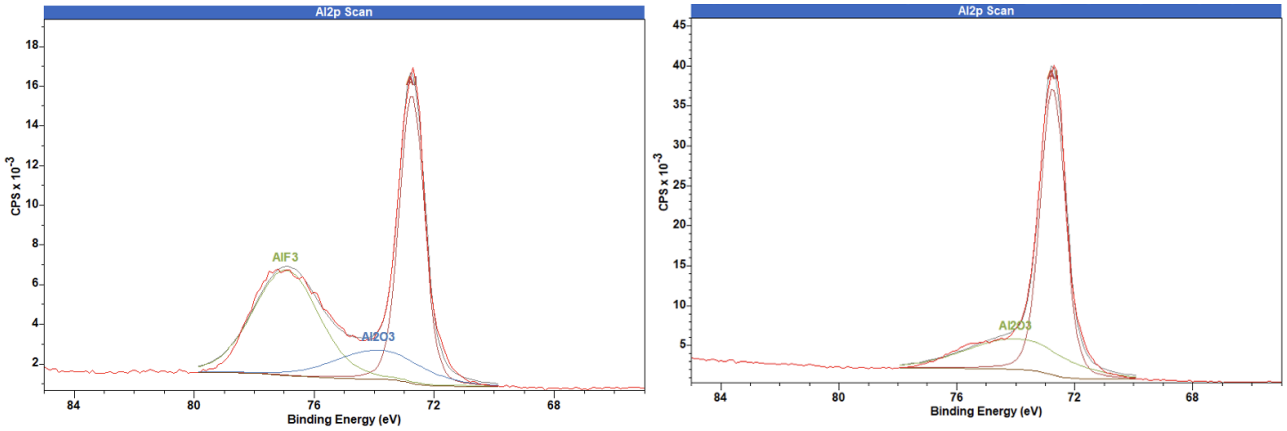


Figure 5: The XPS analysis performed on Si wafers coated both with 40 nm of bare Al. The left panel is for a sample that was treated with XeF_2, while the panel on the right is for same sample with the AlF_3 layer etched away.

3.3 XPS Characterization

Figure 5 shows the result of XPS measurements performed on two Al-coated Si wafers. Both images are from wafers prepared during the same coating run. The panel on the left shows data for the wafer with 30 nm layer of Al after going through the treatment with the XeF_2 fluorination process. The right panel shows a similar Si wafer (coated with 30 nm of Al), but after etching for 20 seconds all the way through the AlF_3 layer. Both panels in Fig. 5 show the main Al peaks (at the binding energy of 73 eV) as well as the Al_2O_3 oxide peak at 74 eV. The panel on the left shows the AlF_3 peak (at 77 eV) that resulted from the XeF_2 gas exposure. The thickness of this AlF_3 layer is estimated to be around 2.5 nm (based on ellipsometric measurements). We should point out that even though both figures show the oxide Al_2O_3 peak at the 74 eV binding energy, the peak intensity for the sample on the left is about half as small when compared to the Al_2O_3 peak in the right side of Fig. 5. The presence of this peak in both images could be attributed to the fact that (as reported by Rodriguez *et al.*) there is some oxygen incorporation during the Al deposition at GSFC due to the water partial pressure in the chamber prior to the Al deposition.[12] Additionally, the AlF_3 is so thin (around 2.5 nm in the just fluorinated samples) that oxygen may still penetrate over time through the fluoride layer to form a combined "oxyaluminum fluoride" layer on top of the Al.[21] Furthermore, we have seen evidence of sample instability by observing a degradation in FUV reflectance as a function of time of these XeF_2-treated Al samples. This degradation is a sure indication that some type of oxidation may be forming on the surface of the sample.

Temperature	Relative Humidity
60°C	0%
3°C	26%
20°C	0%
20°C	30%

Table 1: Environmental conditions that were used to study aging effects of XeLiF samples grown on Si wafers.

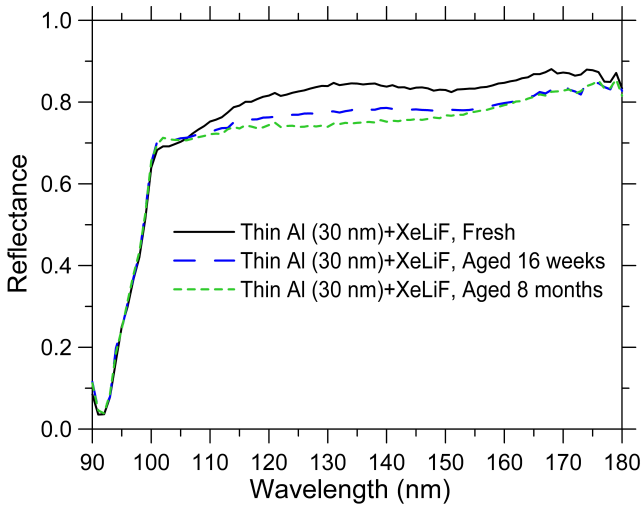


Figure 6: FUV reflectance of the XeLiF sample grown on Si wafer up to a period of 8 months.

3.4 Aging Study of XeLiF with Thin Al Layer

In addition, we performed an aging study of some XeLiF samples grown on Si wafer with the following thickness parameters: Al (30 nm)+AlF_3 (2.5 nm)+ LiF (14 nm). Several of these samples were subjected to certain temperature and humidity conditions (as shown in Table 1). The Al layer was intentionally made thin to better highlight the effect of potential oxidation on the passivated and LiF-protected Al samples. An additional study was performed under more aggressive temperature and relative humidity conditions that is reported by Lewis

et al.[22] The main conclusion here is that the XeLiF coatings had exhibited little degradation when stored in the combined temperature and relative humidity conditions listed in Table 1. Furthermore, samples have been stable under certain conditions (cool temperature and high humidity) as reported by Lewis et al.[22] In other words, XeLiF samples could be kept stable without much degradation at low temperatures (T $<$ 20°C) and relative humidity condition parameters below 50−60%. Since clean rooms generally are at room temperature and have 40-65% RH to preserve electrical components, this means that XeLiF would be stable in most clean-room environmental conditions. The second observation is that XeLiF would be relatively stable in a heated temperature environment (up to 60°C), but at 0% relative humidity. While a temperature of 60°C may not be representative of a "livable" environment, many mission launch sites regularly experience temperatures up to 40°C with high relative humidity ($>$ 50%). The study performed by Lewis *it al.* also reached a conclusion that storage temperature appears to play an important effect in degradation along with humidity. If elevated temperatures can be avoided these studies suggest that a XeLiF coating may be able to withstand elevated humidity at least for a few months. These results point to the resiliency of the rPVD coating process given the stable behavior seen in these samples with the Al layer as thin as 30 nm.

Figure 6 shows the environmental stability of the XeLiF sample with the thin Al layer mentioned above. This sample was stored for a total of 8 months in an uncontrolled laboratory environment with a relative humidity between 45-55% and ambient temperature of around 25°C. The sample retained its peak reflectance of approximately 65% at 100 nm. This sample experienced significantly less degradation than conventional Al+LiF, despite having a very thin Al layer. We hypothesize that the degradation observed in Fig. 6 at wavelengths between 110−180 nm may actually be due to molecular (hydrocarbon) contamination, given the fact that no special care was taken for keeping the sample pristine over the 8 months it had been stored in the lab.

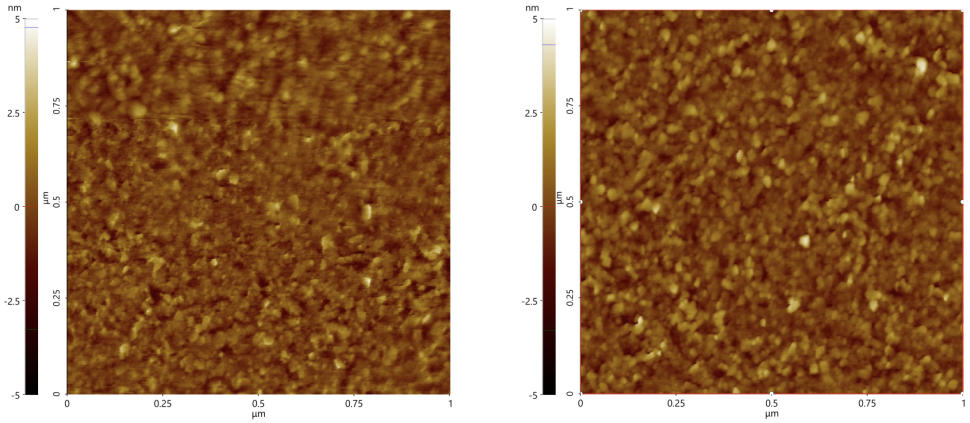


Figure 7: AFM surface topography scans (1μm $\times$ 1μm) of the XeLiF sample with a 30 nm Al layer grown on Si wafer. The surface profiles on the left and right show sample has remained stable (in terms of surface RMS roughness) over 8 months.

3.5 AFM Characterization

Figure 7 shows the results of Atomic Force Microscopic (AFM) characterization performed on the XeLiF sample discussed in Section 3.4 above. These results show the surface characteristics of this sample have remained stable over the 8 months period. The surface root mean square roughness has remained constant (approximately 0.7 nm) between the time when the sample was fresh and after 8 months of storage in an regular laboratory environment. Furthermore, there is no evidence of surface swelling or pinholes in this aged sample.

4. CONCLUSION

In summary, the rPVD process presented in this work offers new features that were not possible before with the conventional PVD coating process. We have obtained state-of-the-art protected-Al mirrors with unparalleled FUV reflectance performance and stability. We are reporting reflectance mirror performance that is over 90%

at the Lyman-alpha wavelength of 121.6 nm for Al protected with LiF and over 95% with a mirror protected with an MgF_2 overcoat. Importantly, the entire process is carried out at ambient temperature. This is a scalable process, limited only by the size of the coating chamber where the passivation (with XeF_2) and evaporation of the metal-fluoride overcoat (LiF or MgF_2) would be carried out. Therefore, the implementation of this process for large area optics is quite feasible where one of the main challenges would be to demonstrate the required uniformity of the Al and the metal-fluoride overcoat over a meter-class mirror substrate. The mirror protected with LiF would offer the highest reflectance at the lowest wavelength of 100 nm. This will open the possibility of scientific observations down to this wavelength, which will be the target of the recently proposed HWO mission concept.

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