Possible mirror coatings for POLLUX

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Max Planck Institute for Solar System Research

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Possible contribution to the UV Spectropolarimeter by Max Planck Institute for Solar System Research:

VUV mirrors (i.e., collimators), coatings, and MgF_2 transmission plates.

MAX-PLANCK-GESELLSCHAFT

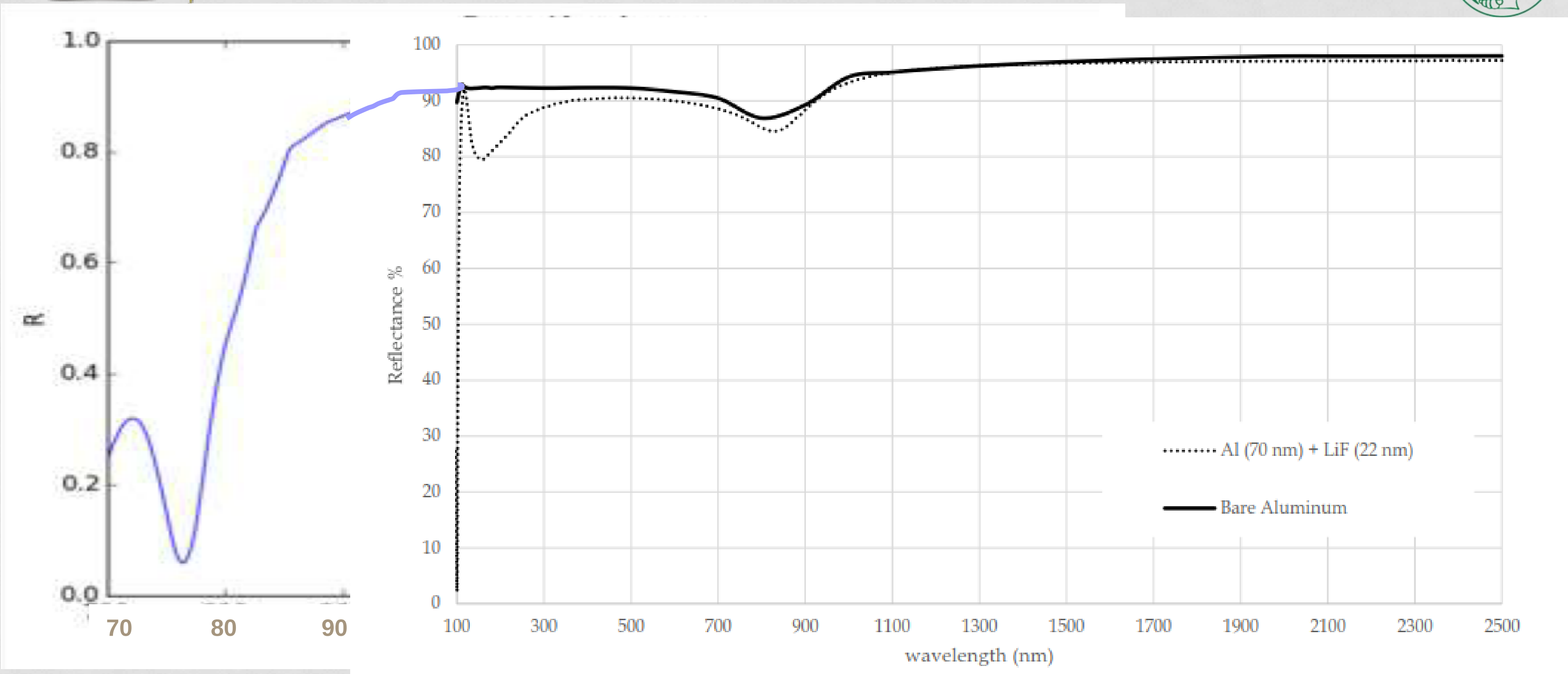
Overview and Requirements of POLLUX mirror coatings

- shortest wavelength far below 120 nm (down to 98 or 90 nm?)
- highest efficiency in the VUV range
- low polarization under normal incidence
- stable under laboratory and space environments

Mirror Coating Options

1. bare aluminium coating without oxide layer
2. aluminium with thin top layer coating (to extend range towards lower lambdas)
3. protected aluminium coatings with MgF_2, LiF, AlF_3, or others

1. bare aluminium coating without oxide layer



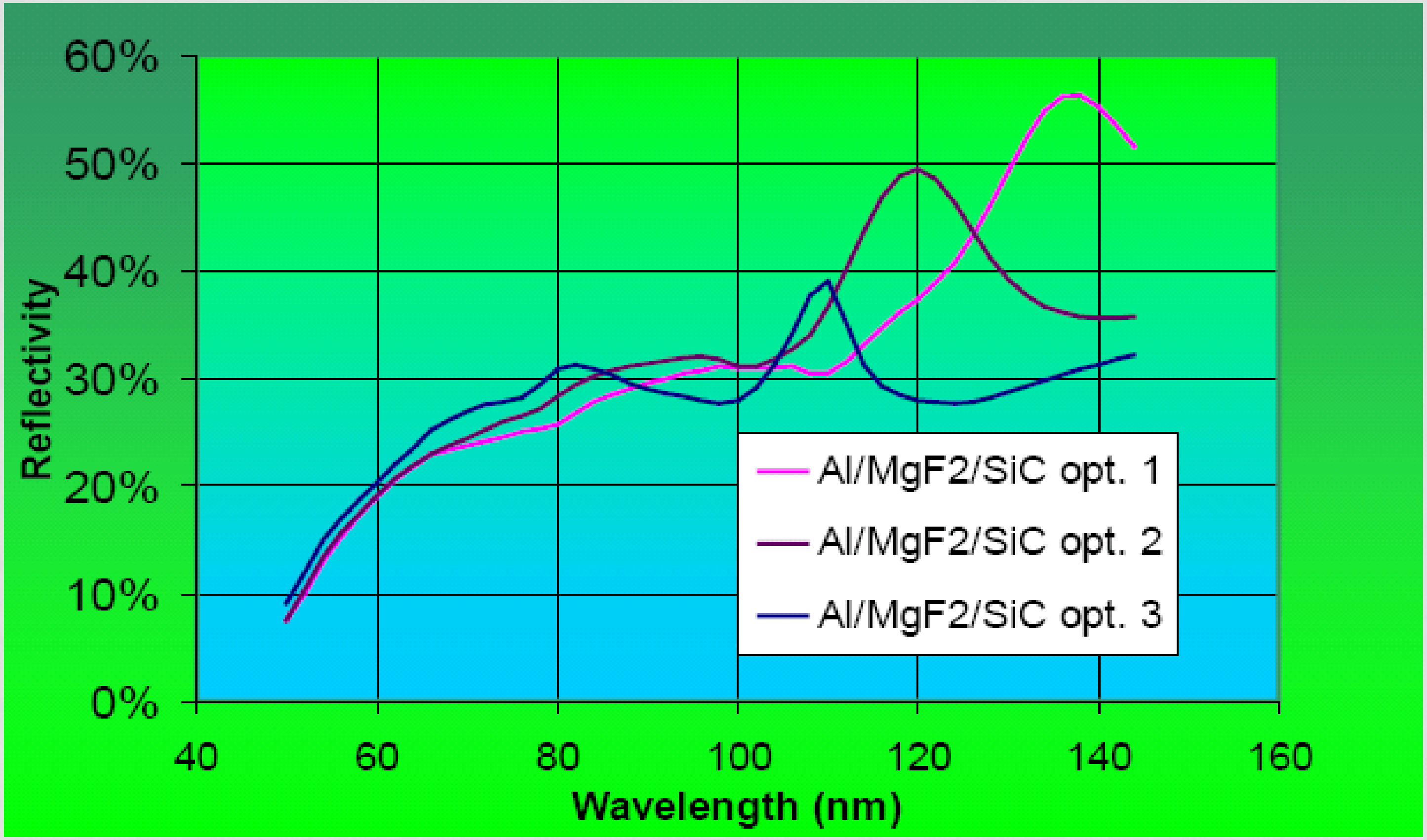
Bare aluminium is the only material with high reflectance for VUV-NUV-Vis-IR range. It‘s reflectance degrades fast with exposure to oxygen.

Possible solutions:

- deposit fresh aluminium in space
- remove protective coating in space:
    - e. g., by plasma etching of a-SiC, mechanical removal of polymer coating)

2. aluminium with thin top layer coating

- thin top layer coating of SiC or B_4C

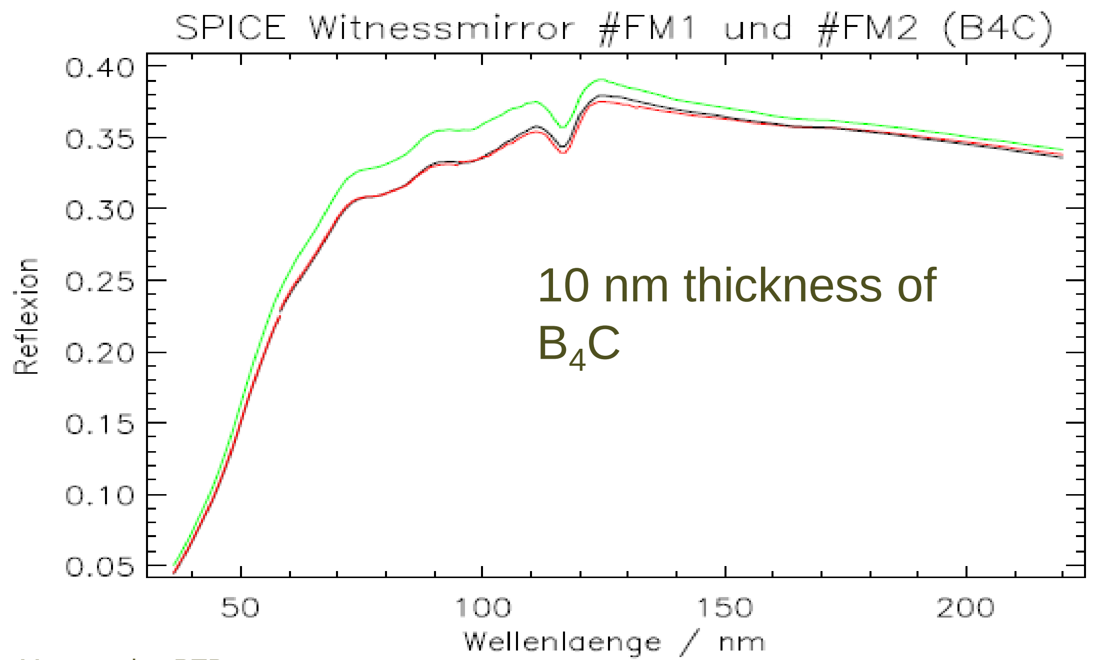


optiX fab.

absorption is not negligible…only justified for wavelengths below 100 nm!

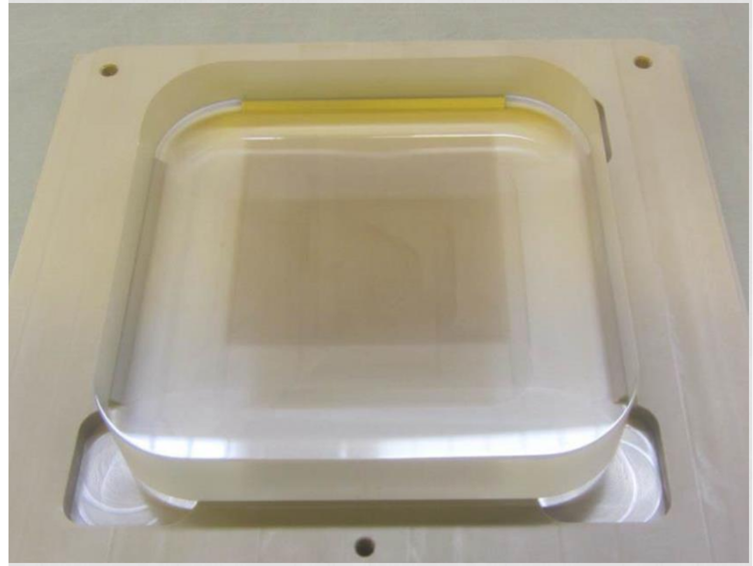
2. aluminium with thin top layer coating

VUV reflectance of thin boron carbide (B_4C) coating but on quartz



10 nm thickness of B_4C

Measured at PTB



optiX fab.

absorption is not negligible…only justified for wavelengths below 100 nm!

3. Aluminium mirrors protected with MgF_2, LiF, AlF_3

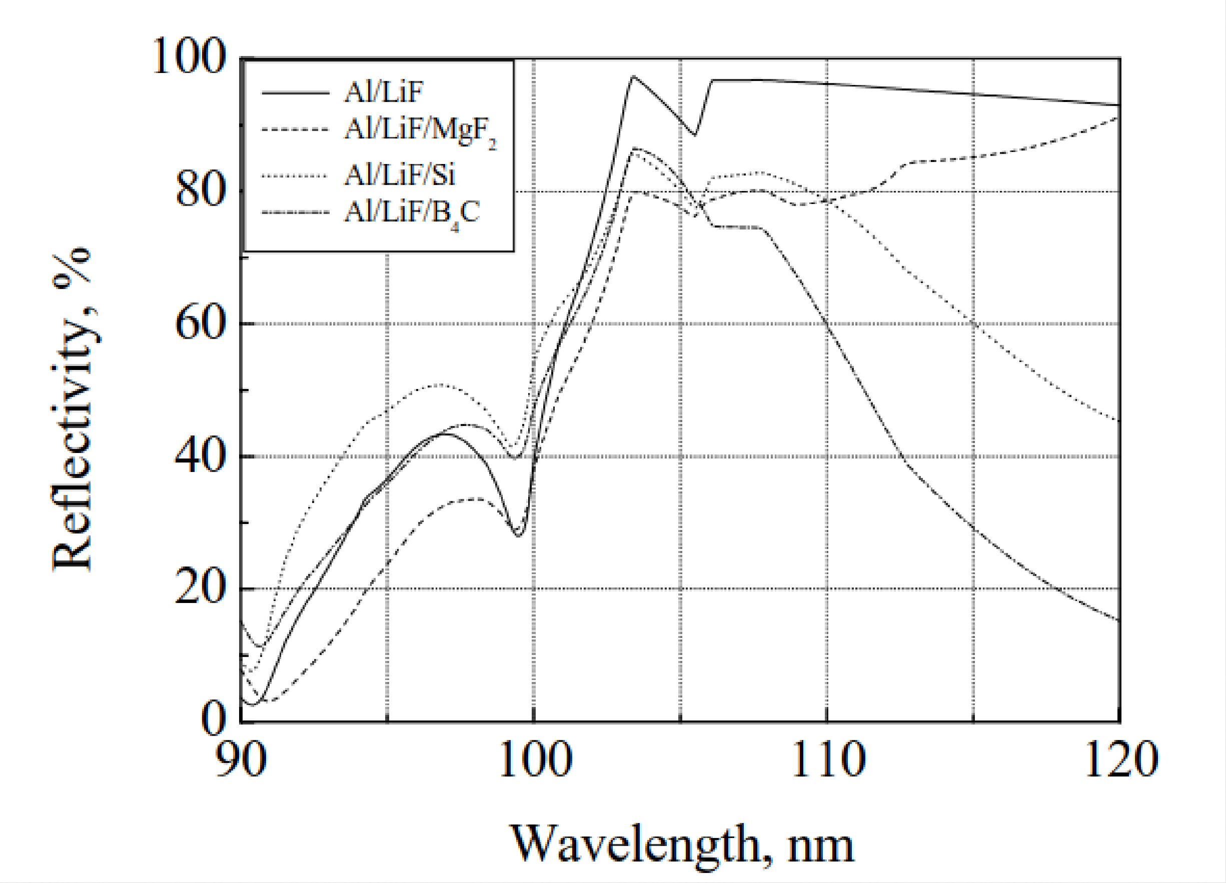
- is presently the baseline for LUVOIR

Strategy to avoid aluminium oxidation:

- deposit protective layer with transparent materials (MgF_2, LiF, AlF_3)
- apply immediately after aluminium deposition
- avoid transfer between deposition chambers
- apply protective coating fast, with high deposition rate
- make layer as thin as possible to minimize absorption
    - ➢ study deposition processes
    - ➢ study thickness dependence
    - ➢ study deposition temperature dependence

3. aluminium protected by thin top layer coating

Al mirrors with top layers optimized for 106 nm at 45° angle of incidence



(Taracheva, Yulin, Feigl, Kaiser, Proc. SPIE 6705, 2007)

Protected aluminium coatings with MgF_2, LiF, AlF_3

Coating designs:

- Coatings with bi-layer protective coatings have been fabricated with combinations of MgF_2, LiF, AlF_3, e. g., Al/LiF/MgF_2…Al/AlF_3/MgF_2…Al/LiF/AlF_3…

- Coatings with single-layer protective coatings have been fabricated with better performance

Deposition processes:

- Resistive evaporation
- e-beam evaporation
- Ion beam sputter deposition
- Evaporation at high substrate temperature (300 °C)
  → more uniform layer, no pin holes, lower thickness needed
- Atomic Layer Deposition (ALD)
  → more uniform layer, even lower thickness needed, slower deposition

Protected aluminium coatings with MgF_2, LiF, AlF_3

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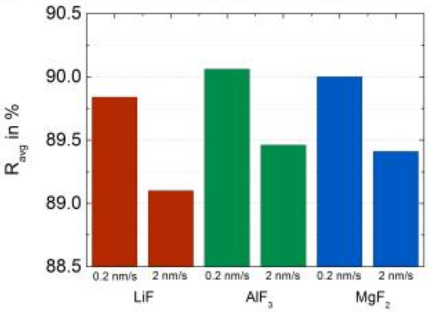
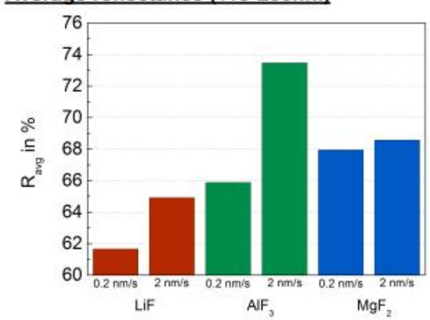
Protected aluminum mirrors

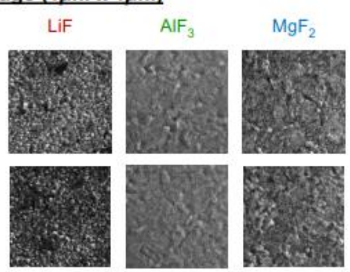
Average reflectance (200-850nm)



Average reflectance (115-200nm)

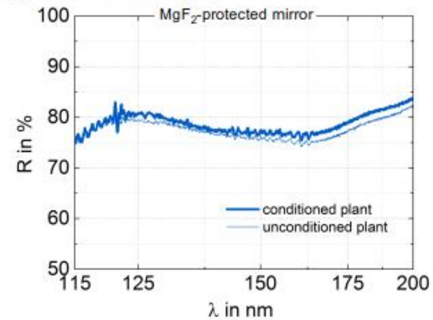


SEM-Image (1µm x 1µm)

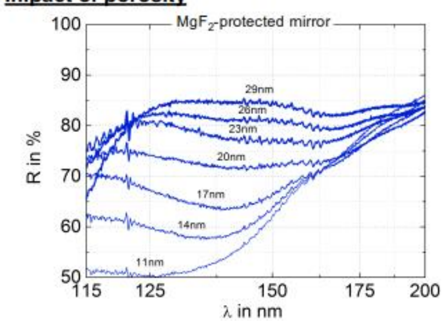


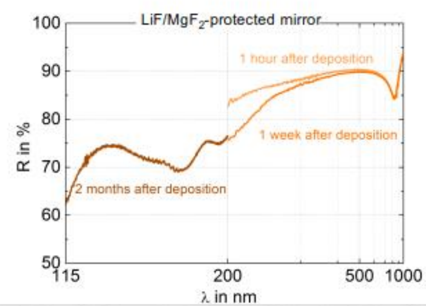
Degradation effects

Impact of residual gas



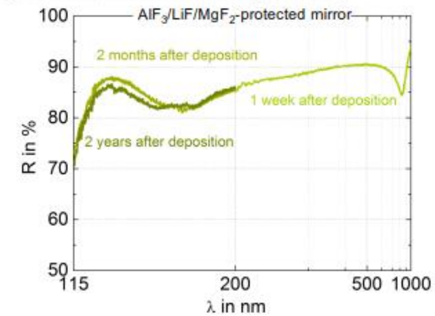
Impact of porosity



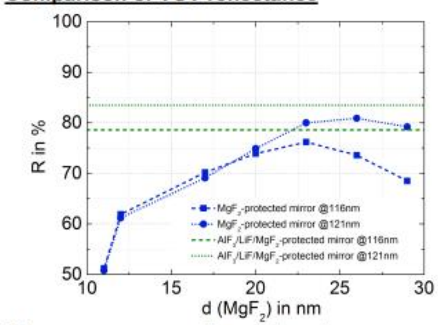


Derived system

System with minimized degradation



Comparison of VUV reflectance



Summary and outlook

Different metal fluorides have been investigated as a protective coating for aluminum mirror in the VUV spectral region. Lowest surface roughness even at high deposition rates makes AlF_3 well suited for this. An increased VUV reflectivity of such mirrors has been validated.

Acknowledgement

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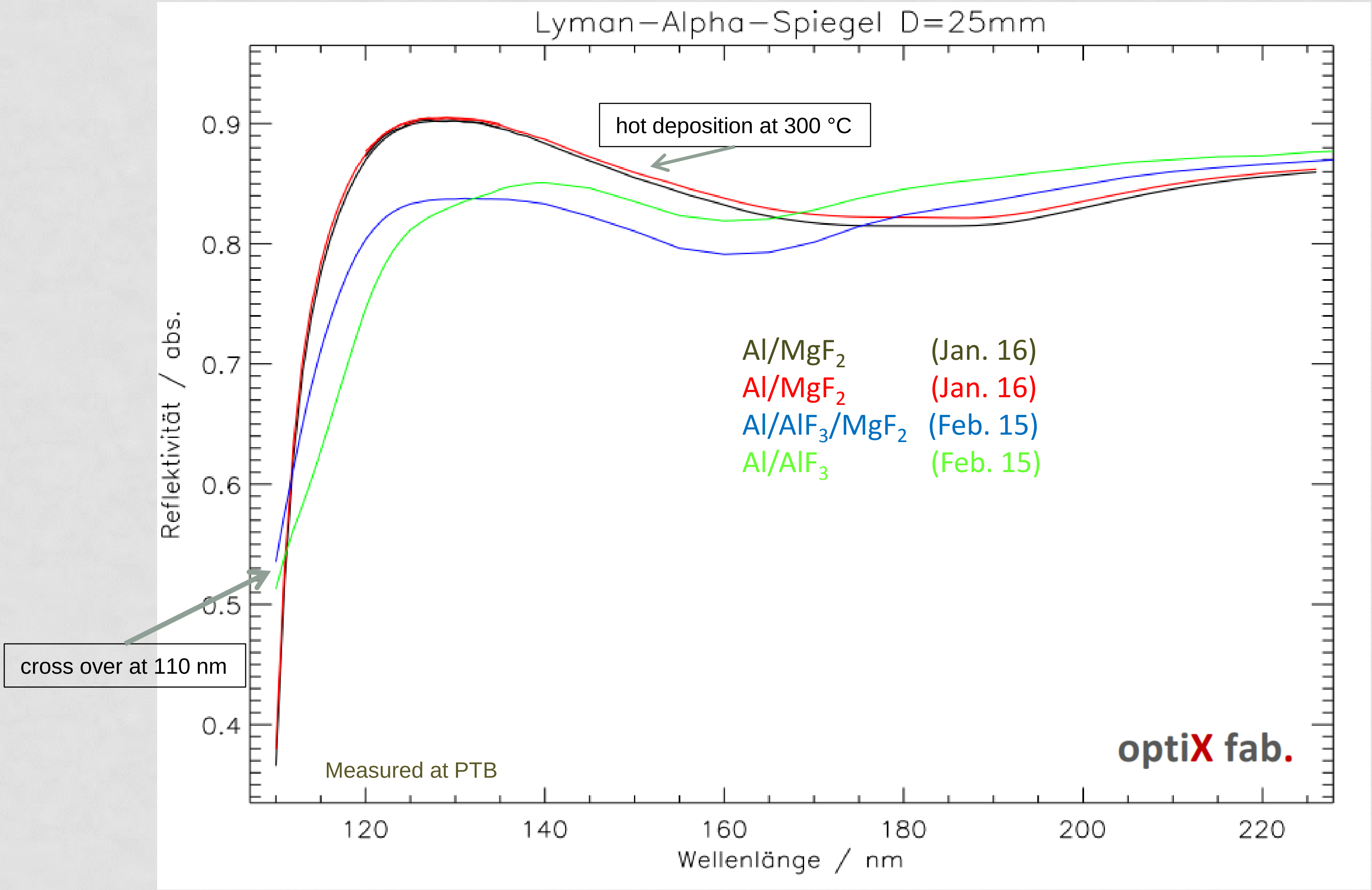
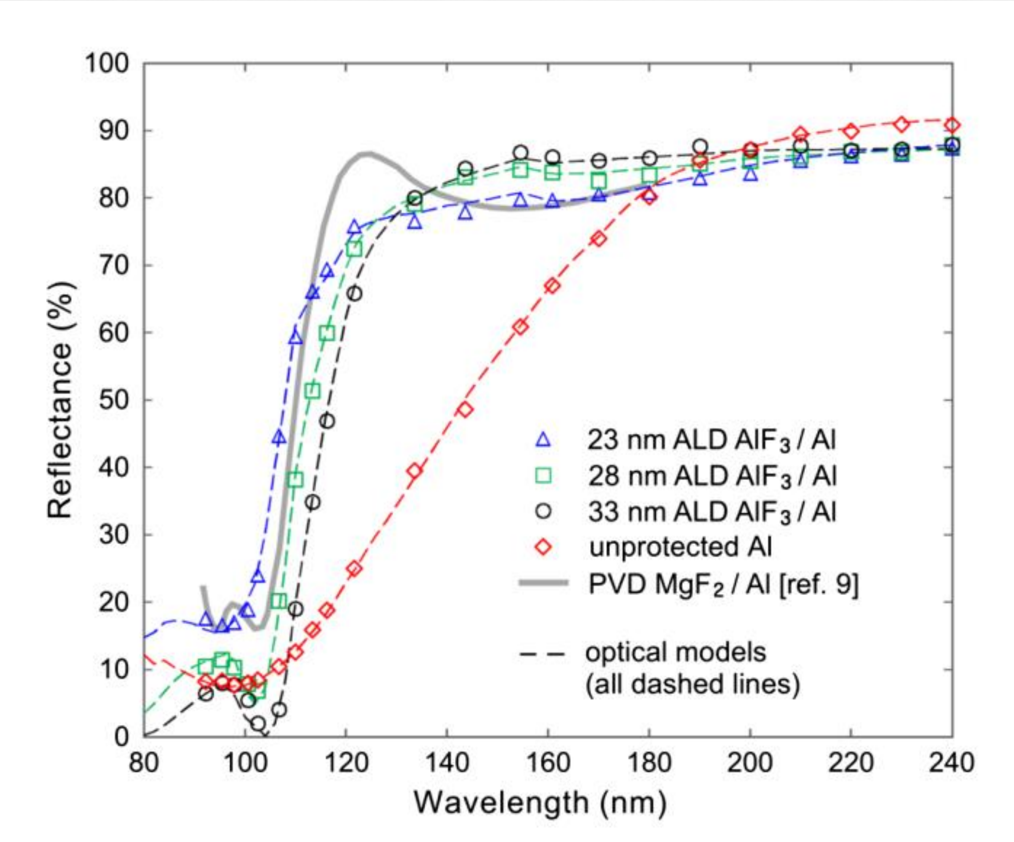
Mirror coatings with protected Aluminium optimized for Lyman-a



Protected aluminium coatings with AlF_3

Al/AlF_3 - the most promising candidate for reflectors below 110 nm



ALD AlF_3/Al at various thicknesses
- thinner layer gives higher reflectance

(Hennessy et al., JATIS 2(4), 2016)

Protected aluminium coatings with AlF_3

Al/AlF_3 - the most promising candidate for reflectors below 110 nm

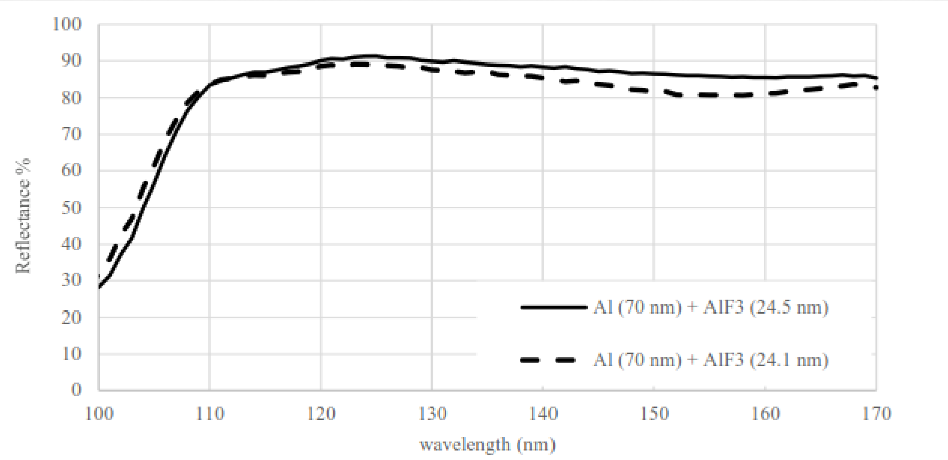
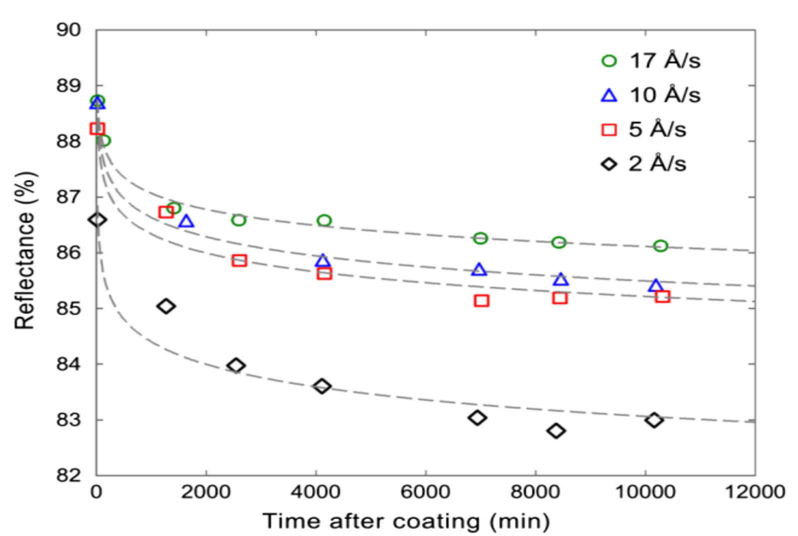


Figure 3. FUV Reflectance vs. Wavelength of deposited Al+AlF_3 samples.

Deposition of AlF_3 at 250°C substrate T

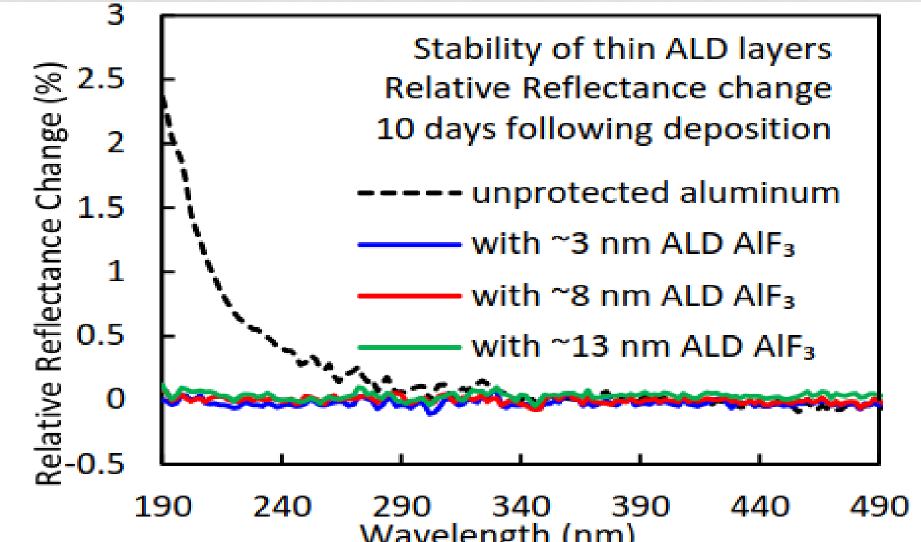
(Quijada et al., Proc. SPIE, 10372, 2017)

Dependence of degradation on Al deposition speed



(Hennessy et al., JATIS 2(4), 2016)

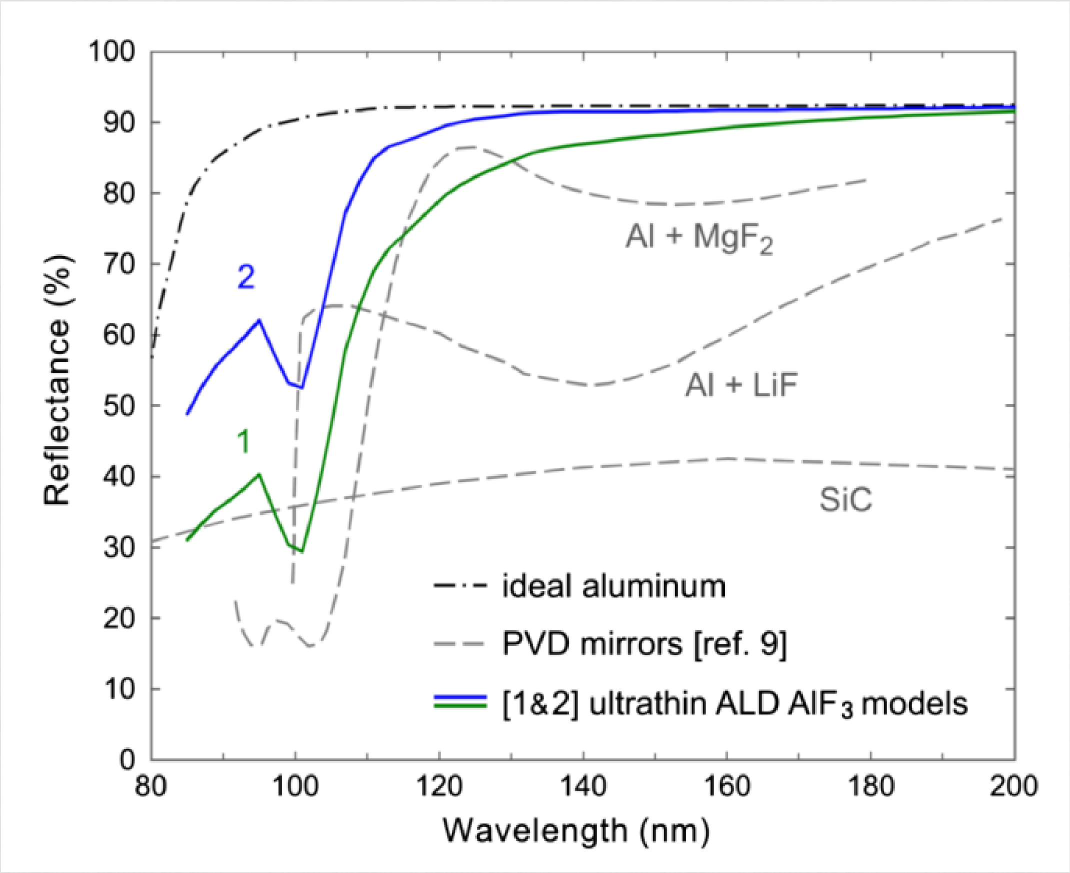
Dependence on layer thickness of ALD AlF_3 deposition



(Balasubramanian et al., Proc. SPIE 9602, 2015)

Protected aluminium coatings with AlF_3

- prospective performance -



(Hennessy et al., JATIS 2(4), 2016)

Predicted performance of Al mirrors protected by ultra-thin ALD AlF_3 using the optical models in comparison to the theoretical performance of ideal (unoxidized) Al and to existing demonstrations. Curve 1: 3 nm of ALD AlF_3 assuming 3 Å of interfacial Al oxide. Curve 2: 2 nm of ALD AlF_3 assuming no oxide

Protected aluminium coatings with AlF_3

- state of the art -

Aluminium tri-fluoride as a Protection Layer

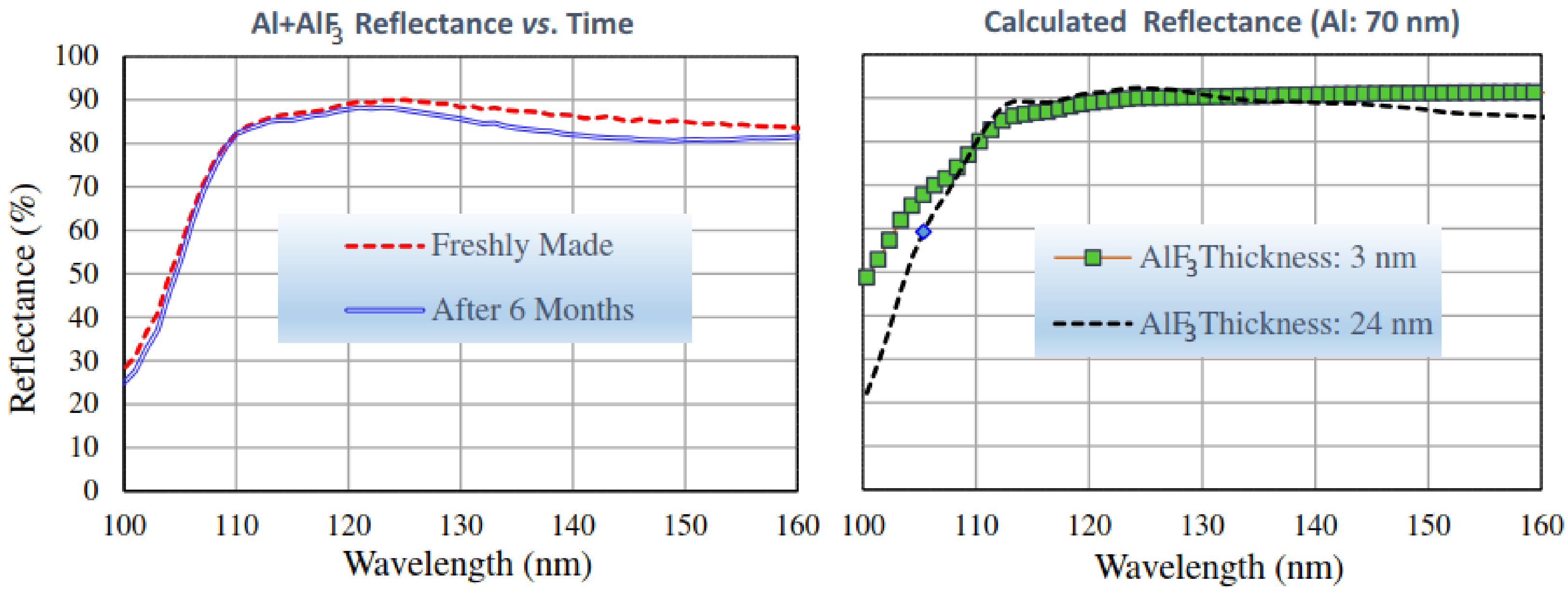


Figure 6. (Left) The FUV reflectance of a Al+AlF_3 sample that was prepared with the conventional PVD process. These results show vey little changes after sample was kept in ambient laboratory conditions for more than six months. (Right) Predicted reflectance based on thickness parameters (Al: 70 nm; AlF_3: 24 nm) of sample shown on the left. The second (green squares) curve shown on the righ panel illustrate the predicted performance of a sample with an AlF_3 layer 3 nm thick.

(Quijada et al., Proc. SPIE Vol. 10398, 2017)

Protected aluminium coatings

Conclusions:

- AlF_3 is a dielectric material with a low refractive index and wide band gap > 10 eV. Because it has a slightly larger band gap (than MgF_2), the AlF_3 gives access to lower wavelengths on FUV reflectors.
- It also has high transmission at infrared (IR), ultraviolet (UV) and deep UV wavelengths.
- AlF_3 is less hygroscopic than LiF, so it will be a more environmentally stable coating.
- The low surface roughness, even at high deposition rates, makes AlF_3 well suited for use in protected and enhanced FUV Al mirrors.
- Highest reflectance at shortest wavelengths will be achieved with AlF_3 coating immediately after aluminium deposition.
- The viability of using AlF_3 as a protection layer to realize high FUV reflectance for Al mirrors has been proven.
- Future systematic studies are to be made to optimise deposition processes and stability of thin coatings.