Recent Progress on 2012 SAT for UVOIR Coatings

2014 Mirror Technology/SBIR/STTR Workshop

By

Manuel Quijada

Outline

- Project Objectives
- Methods & Facilities
- Results
- Conclusions & Future Plans
- Acknowledgements

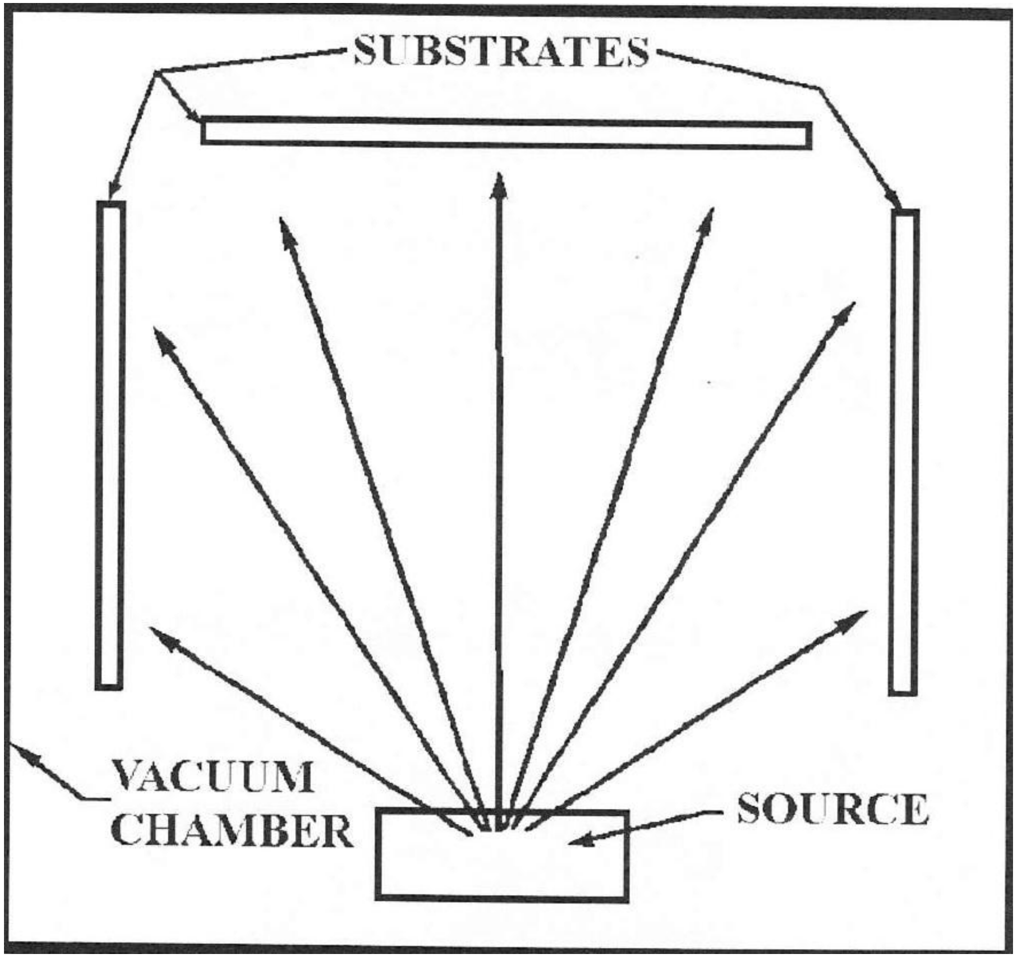
Enhanced FUV Coating Applications

- Distant and faint objects are typically searched for in cosmic origin studies:
  - Origin of large scale structure
  - The formation, evolution, and age of galaxies
  - The origin of stellar and planetary systems
- Astronomical observations in the Far Ultraviolet (FUV) spectral region are some of the more challenging
- Very limited option of reflecting coatings to use at FUV wavelengths:
  - Modest reflectivity offered by those coatings
  - Al+MgF_2 [typically 82% at Lyman-alpha, 1216 Å) that are used on reflecting surfaces of FUV instrumentation
- Improved reflective coatings for optics at FUV could yield dramatically more sensitive instruments .
- Permit more instrument design freedom

Project Objectives

- Develop coating deposition processes to improve performance of mirrors in Far Ultraviolet (FUV) spectral range
- Three specific tasks:
  - Use a reactive Ion Beam Sputtering process to make low scatter MgF_2 films
  - Research little studied low-absorption materials to produced dielectric coatings in the FUV
  - Improve FUV mirror reflectance of aluminum mirrors over-coated with MgF_2 and LiF
- 3-year performance period (Started in FY12)

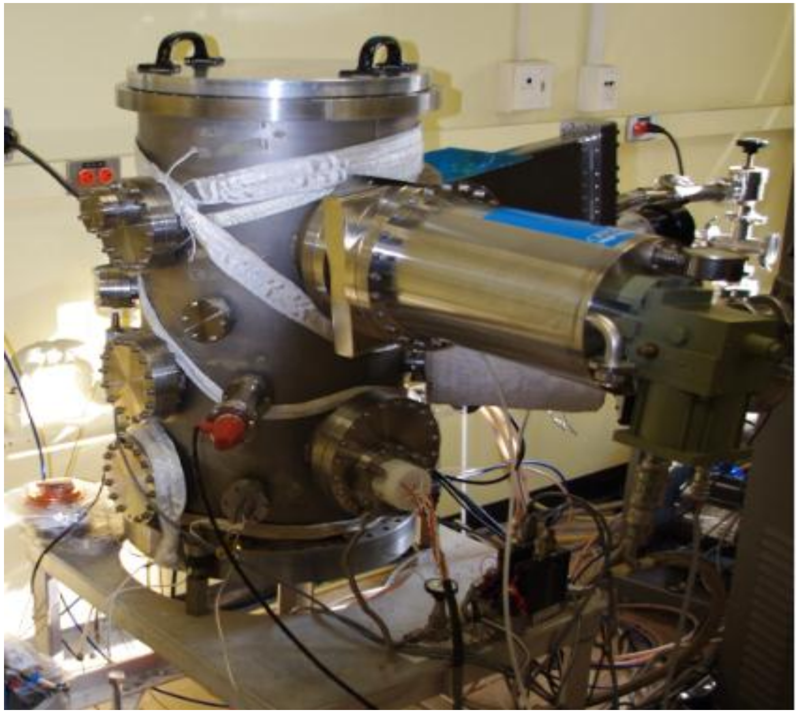
Physical Vapor Deposition



GSFC Coating Facilities

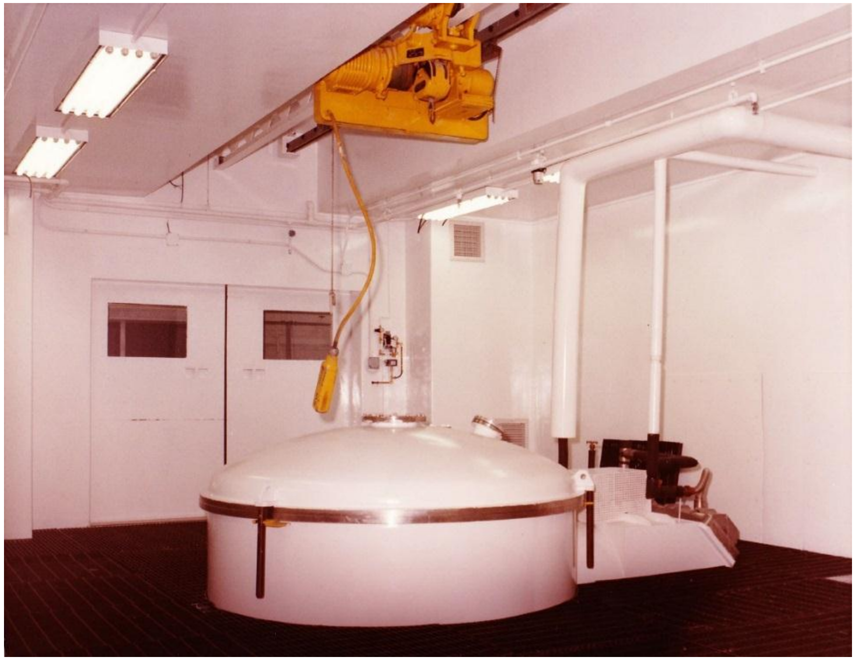
- PVD, IBS, and RF Magnetron Sputtering deposition chambers
- Coatings produced: Al, MgF2,, LiF, SiO_x , GdF_3, LuF_3, Al_2O_3, Ag, Cr, Y_2O_3

PVD coating chamber (1-meter)



Reactive Ion Beam Sputtering

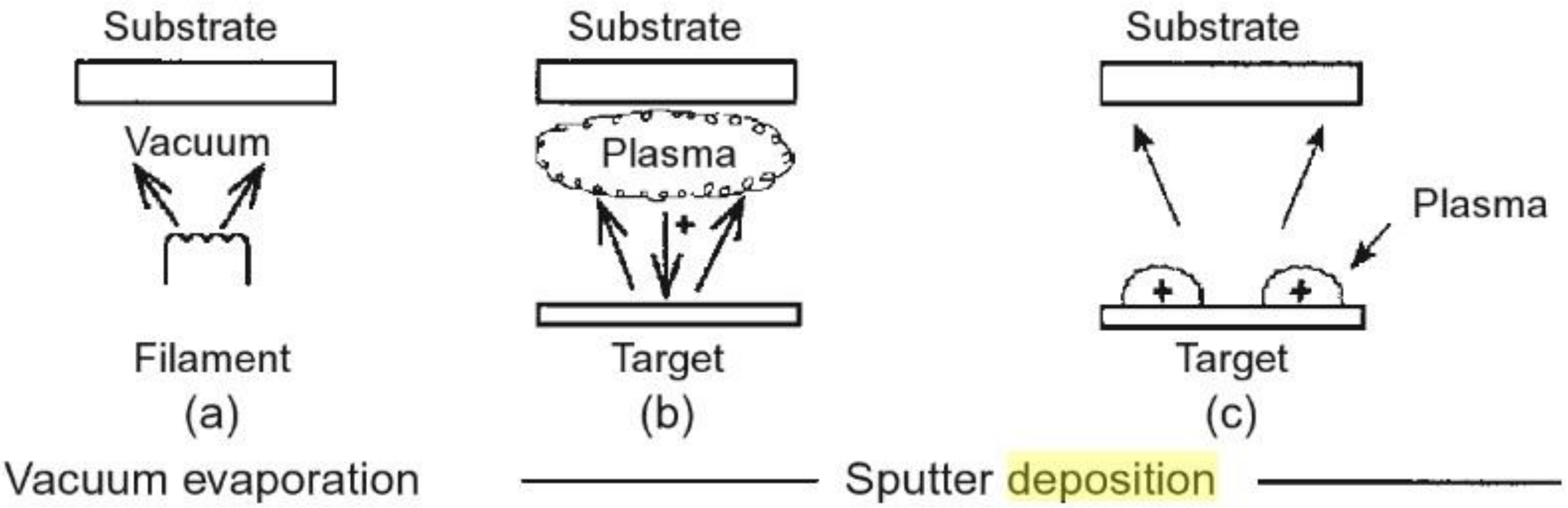
2-Meter Chamber



Chamber top Cover with mirror substrate installed

Missions supported: Astronomical Observatory (OAO) & Ultraviolet Explorer (IUE)
FUSE, HST (COSTAR, GHRS & COS), and a number of sounder rocket missions

Coating Deposition Processes



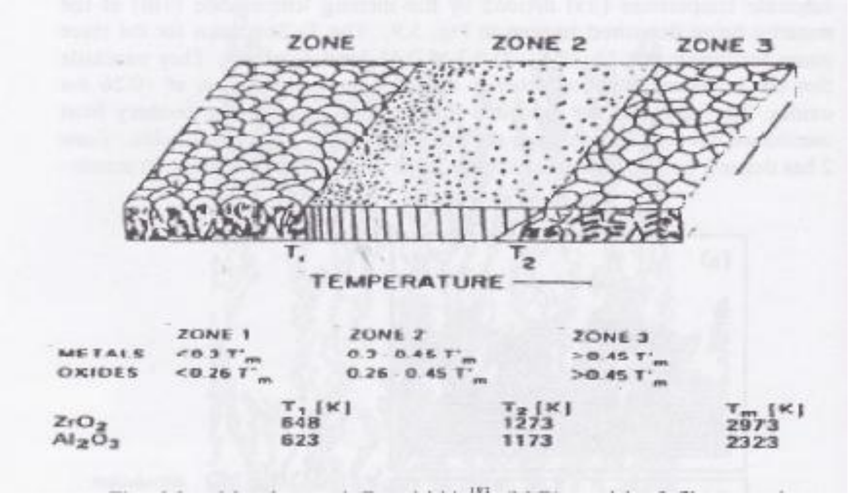
PVD

- Material is heated until it reaches vapor form
- Material is deposited on the substrate where it condenses
- Typical deposition rates are 10-100 Å/Sec.

Sputtering

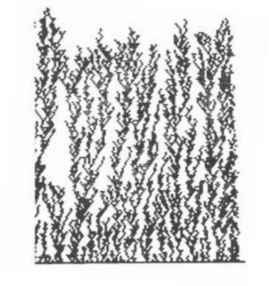
- Non-thermal evaporation process
- Atoms from a target are ejected by momentum transfer from energetic atom-size particles
- Particles are energized by an ion gun
- Deposition rates are much lower than PVD 1-5 Å/Sec.

Model of Film Growth vs. Temperature



	ZONE 1	ZONE 2	ZONE 3
METALS	$<0.3\ T'_m$	$0.3 - 0.45\ T'_m$	$>0.45\ T'_m$
OXIDES	$<0.26\ T'_m$	$0.26 - 0.45\ T'_m$	$>0.45\ T'_m$

	T_1 [K]	T_2 [K]	T_m [K]
ZrO_2	648	1273	2973
Al_2O_3	623	1173	2323



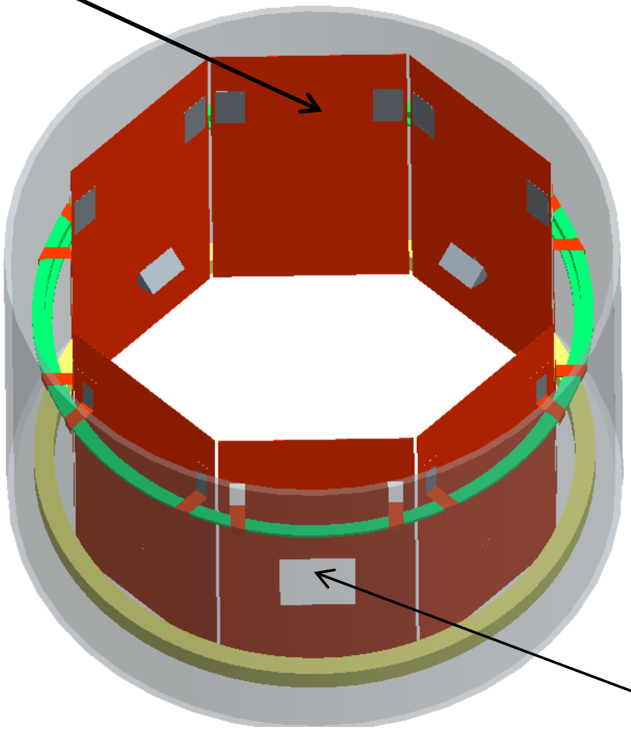
Computer simulation growth process (Karl Gunther)

- Zone model of film growth vs. substrate temperature (After Movchan & Denchishin (1969))
- Three zones as function of Ts/Tm
  - Zone 1 (< 0.25): Feathery “frost” with columnar growth separated by many voids
  - Zone 2 (0.25 to 0.45): Densely packed columns
  - Zone 3 (> 0.45): Polycrystalline structure

2-meter Chamber Heat Panel Concept

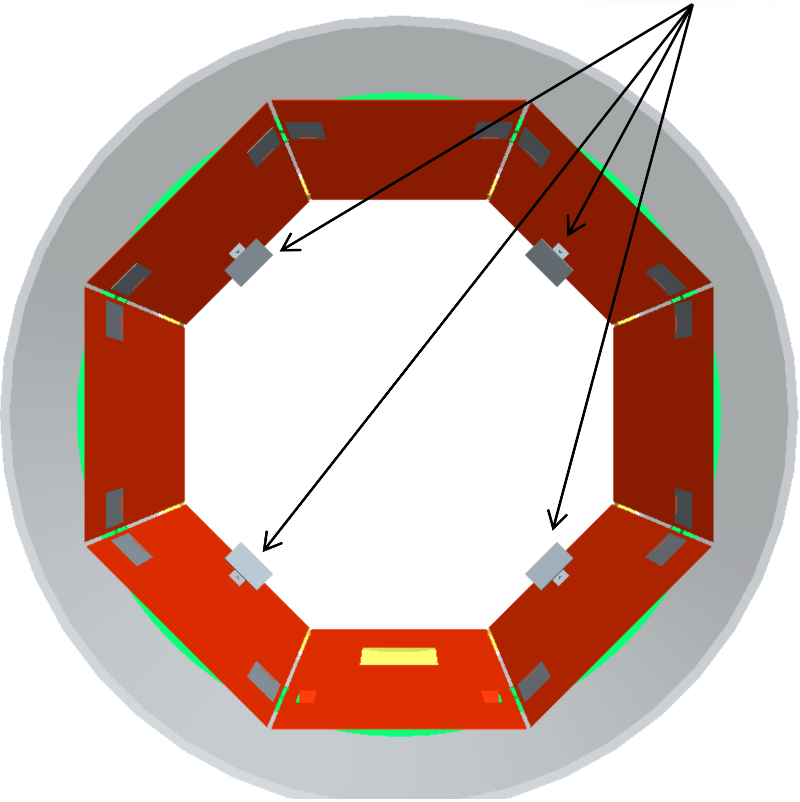
- Design and fabrication of internal heat shields for 2-meter Chamber.
- Optimized coating parameter for high FUV reflectance of a distribution of slides in center and out to a ~0.5 meter radius.
- These wall panels were made out of stainless steel and were designed to easily interface with the existing internal configuration of the chamber.

8 PANELS

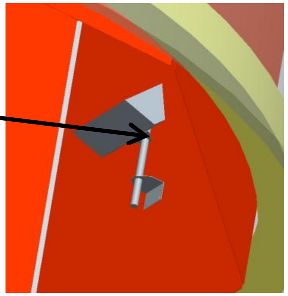


SINGLE VIEWPORT 10” X 10” SQUARE

4X LIGHT MOUNTS

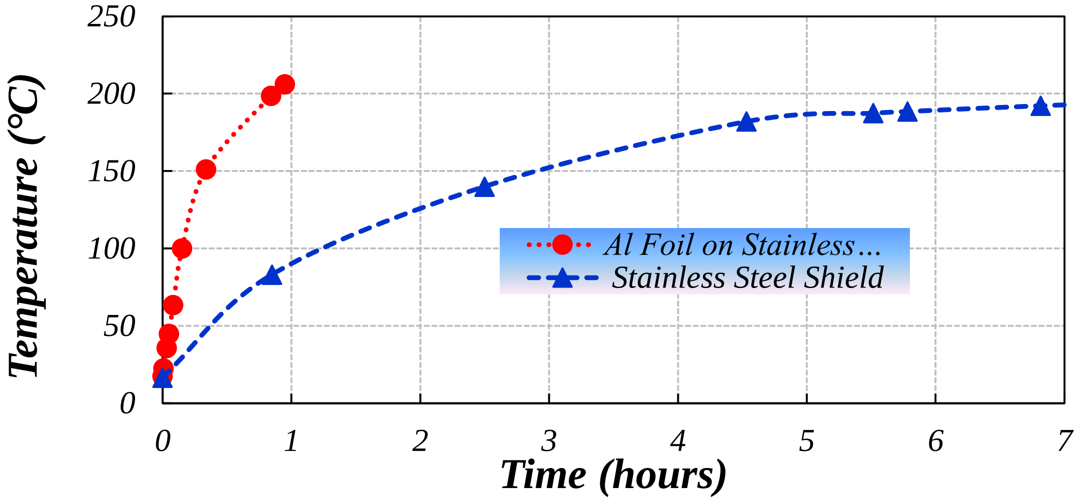


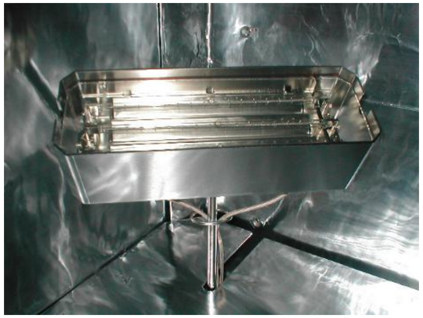
ADJUSTABLE LIGHT MOUNT



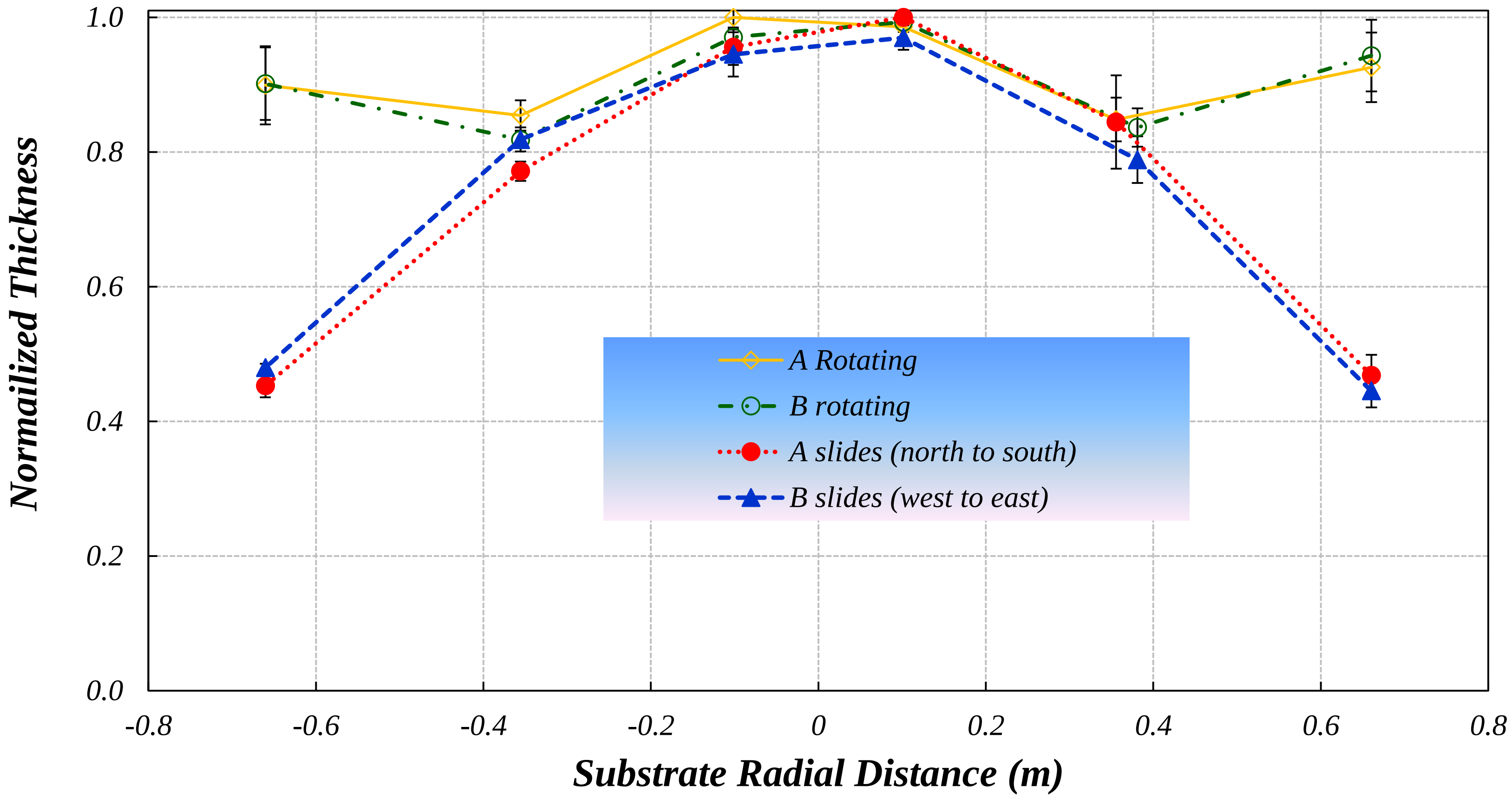
2-meter Chamber Heater Check Out Process

- Earlier test of heaters showed maximum temperature reached was only 100 ° C after 5 hours
- Doubled lamp power output from 500 W to 1000 W each (4000 W total)
- Additional testing yielded a maximum temperature of 130 ° C
- Further testing done after wrapping heat shield panels with **aluminum foil** provide for a much quicker raise in temperature, reaching 220 ° C in less than 1 hour





Thickness Uniformity

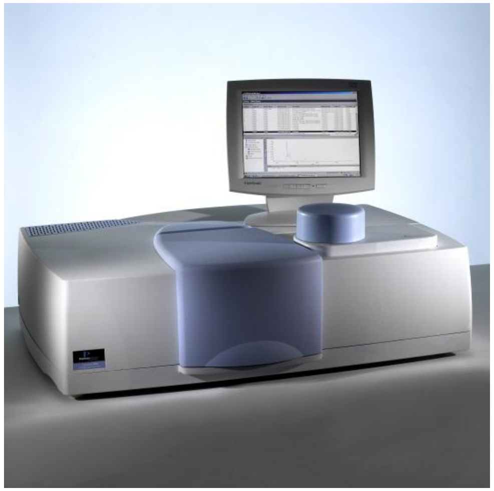


Optical Characterization: T(λ), R(λ)

ACTON VUV Spectrometer

- Spectral range: 30-300 nm
- Source: Windowless H2-purged source (H2 emission lines between 90 nm and 160 nm and a continuum at higher
- Detector: PMT with fluorescence coating

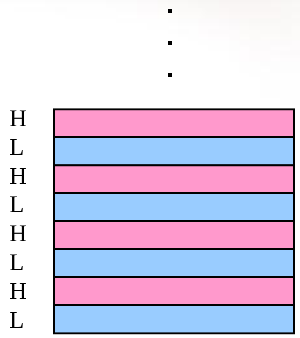
Perkin Elmer Lambda 950



Spectral range: 190-2500 nm
Universal Reflectance Accessory

FUV Reflecting Dielectric

- **Choose a high-index (H) and low-index (L) pair combination**
- **Form a pair of (H,L) layers with thicknesses equal to a Quarter-Wave Optical thickness at the design wavelength.**
- **Repeat the stack above until desired reflectance is achieved.**

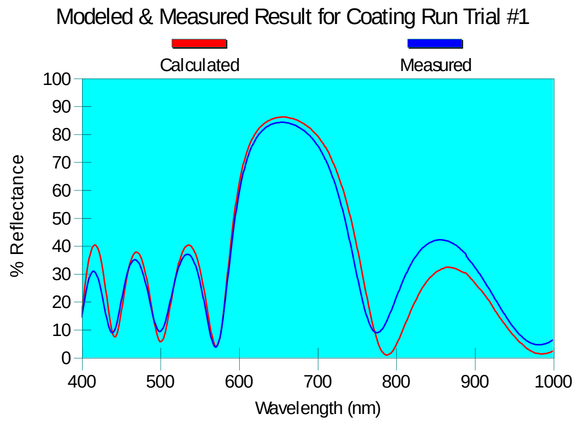


Note: The larger the difference between (n_H-n_L) the better contrast and fewer layers needed to achieve a given R

Options for dielectric materials:

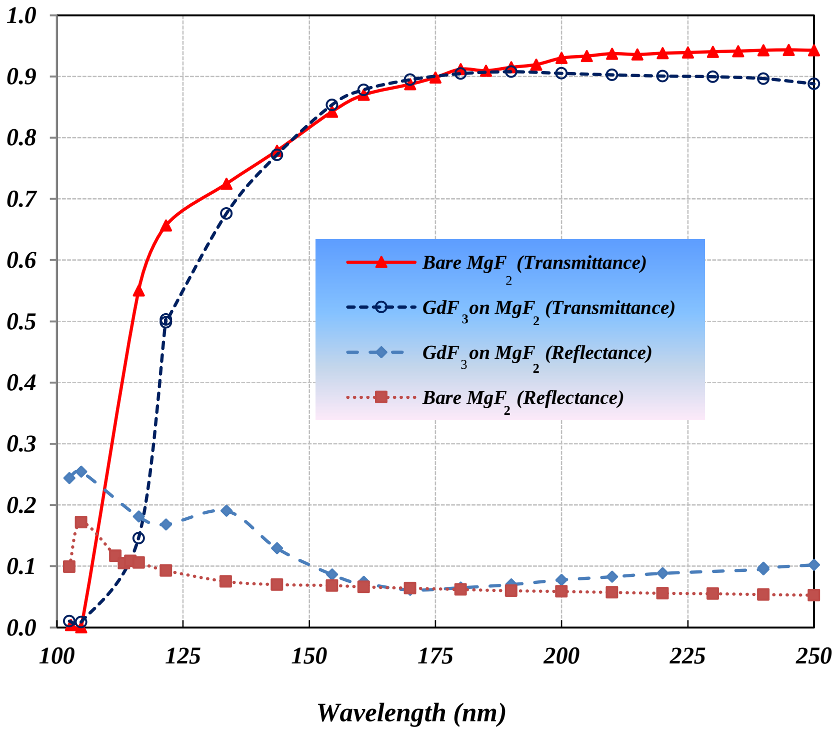
L: MgF_2 (n ~ 1.45)

H: GdF_3; LuF_3 (n ~ ?)

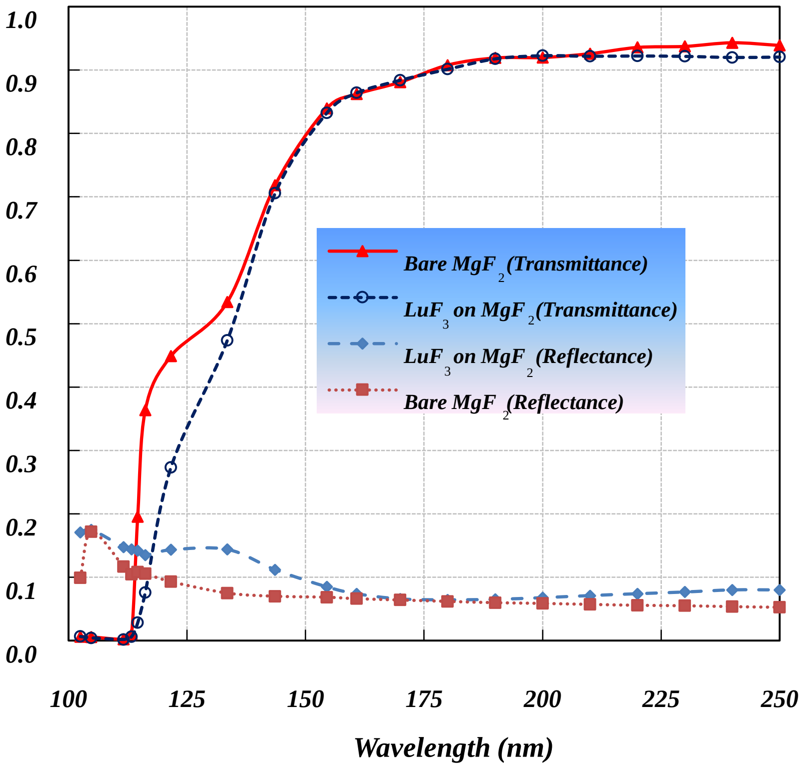


GdF_3 and LuF_3 Films Characterization

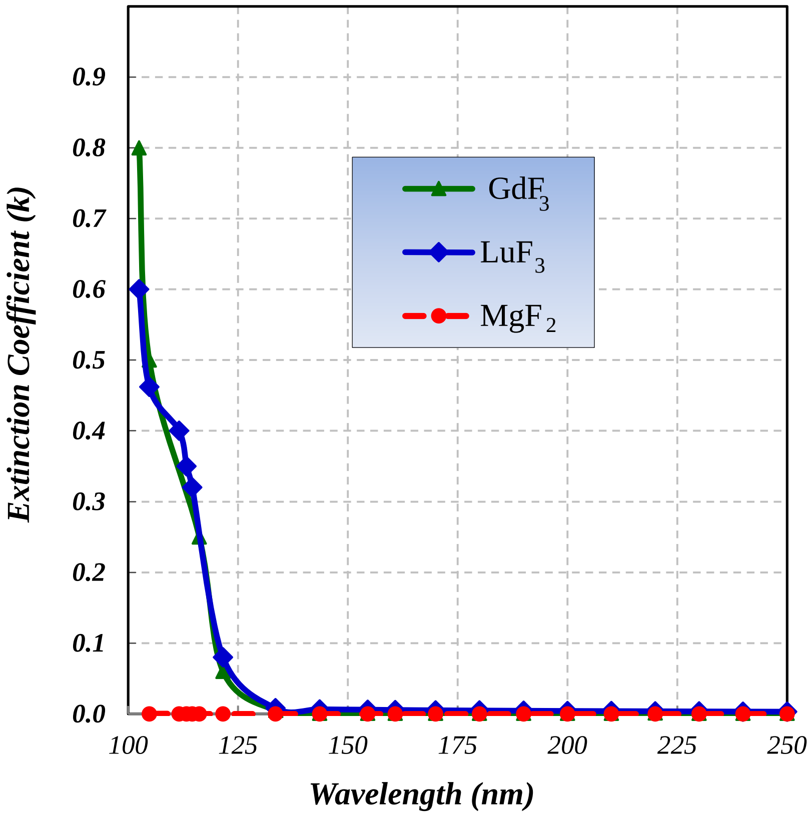
- 430 A GdF3 film on MgF2 substrate

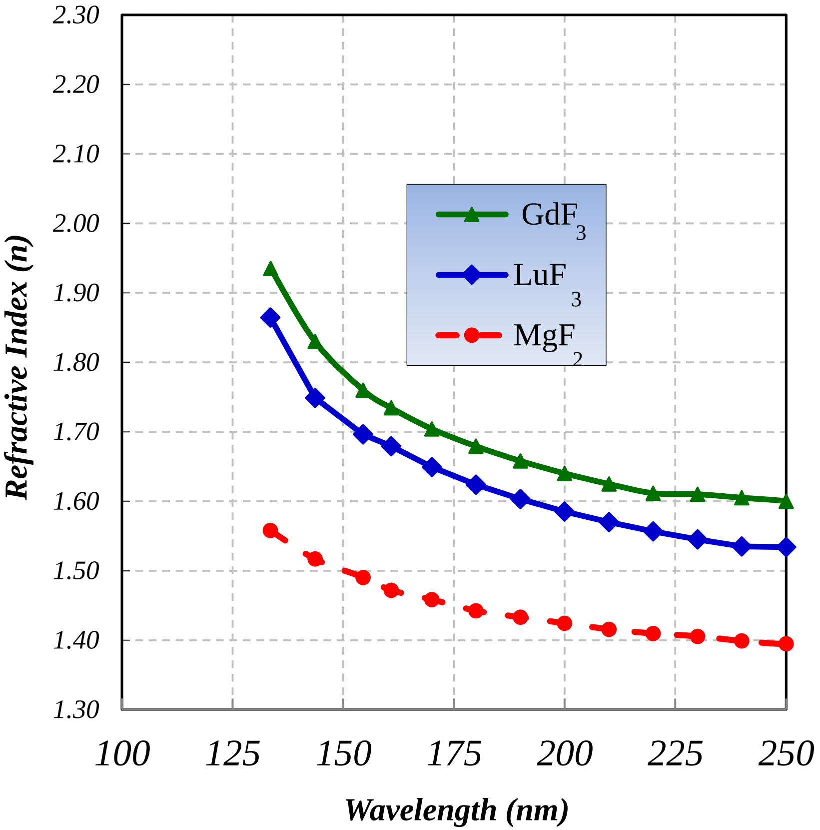


- 435 A LuF3 film on MgF2 substrate

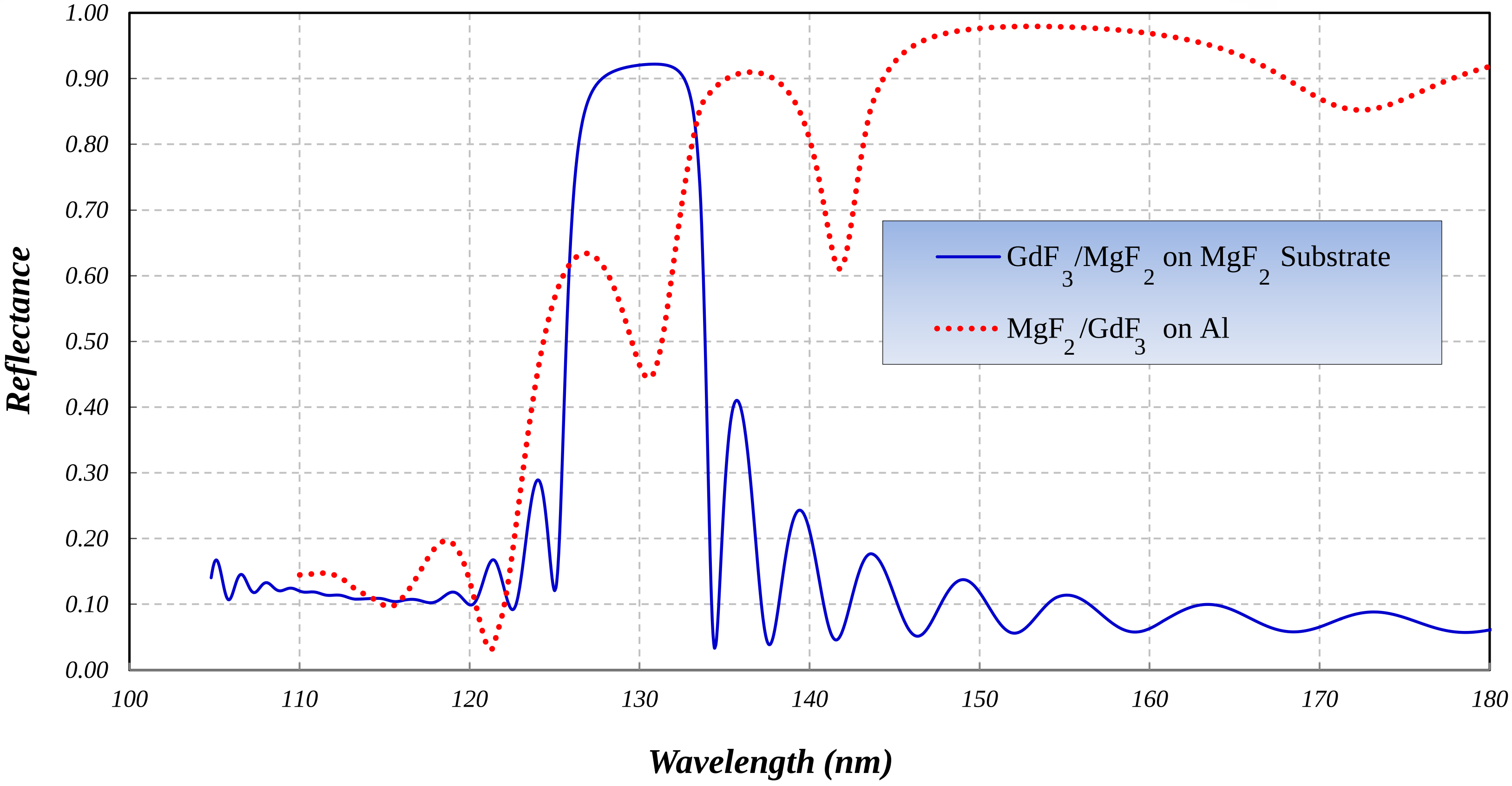


GdF_3 and LuF_3 Films Optical Constants





FUV Reflector

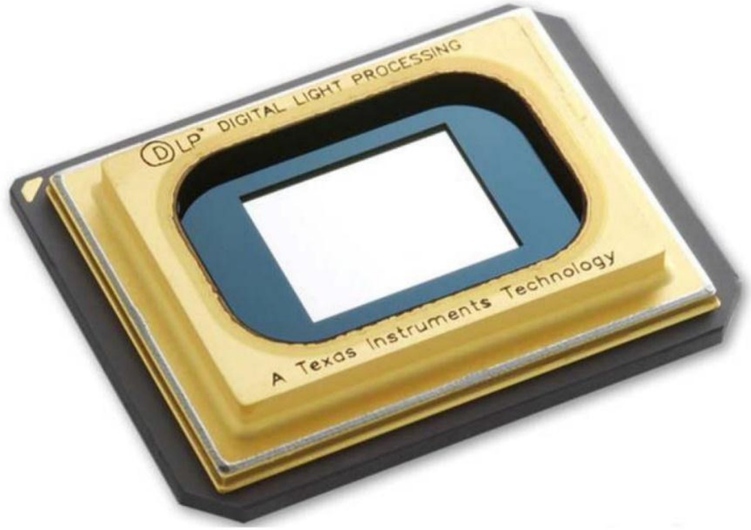


Design 1: 5 pairs MgF_2/GdF_3 on Al layer

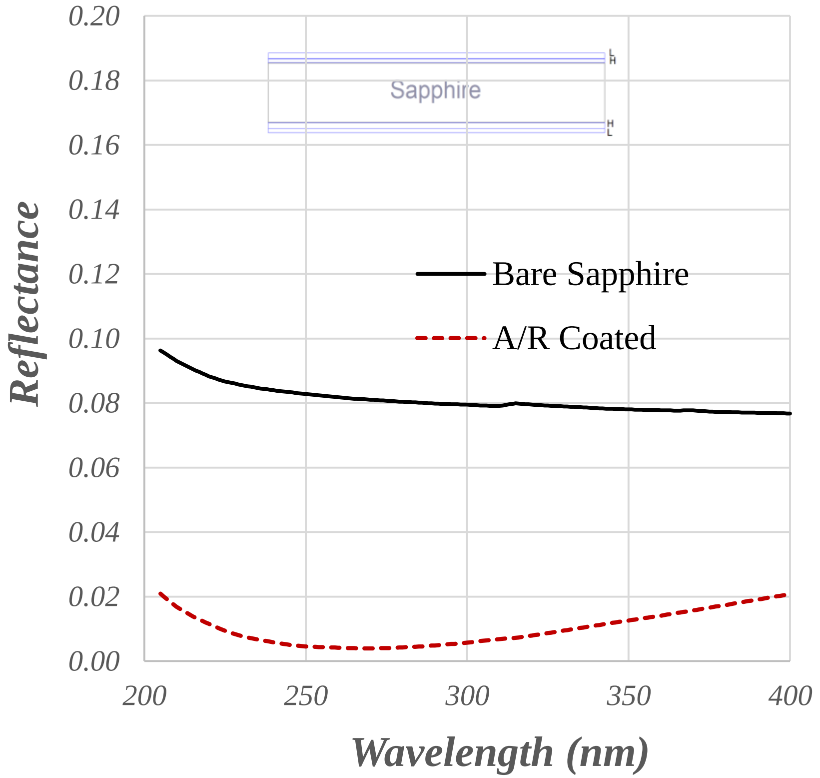
Design 2: 10 pairs MgF_2/GdF_3 on MgF_2 substrate

A/R Coating Application: DMD Windows for UV Astronomy

0.7XGA 12º DDR DMD



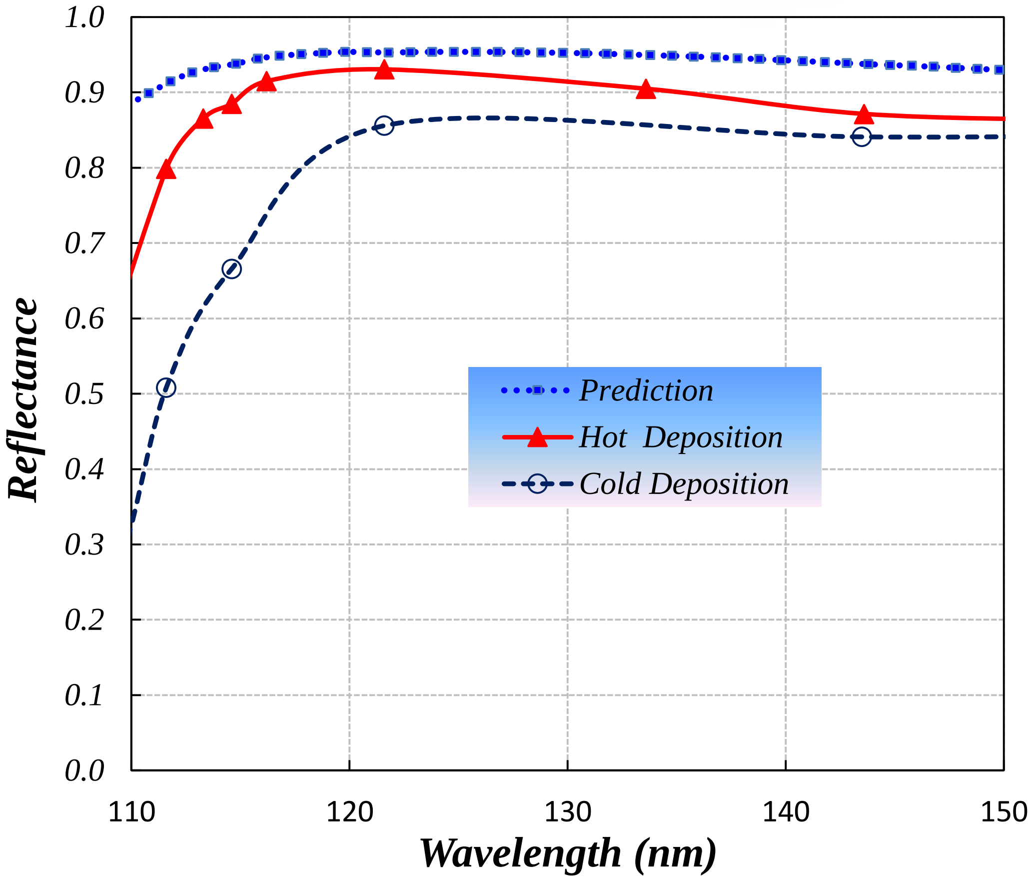
A/R Coating Performance (Per Surface)



- APRA grant (PI: Zoran Ninkov (RIT) to enable use of Digital micro-Mirror Device (DMD) in UV astronomy
- DMD window replacement to allow transmission in the UV spectral range
- A/R coating design on Sapphire: 155.6 A (GdF_3) & 384.6 A (MgF_2)
- A/R

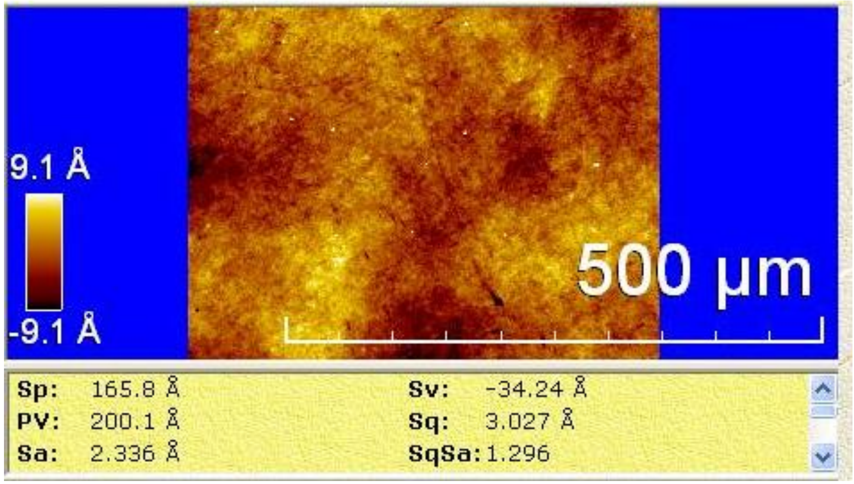
Al+MgF$_2$ Mirror FUV Performance

- Predicted vs. measured reflectance of bare Al and Al+MgF$_2$ reflectance (Al: 50.0 nm; MgF2: 25.0nm)
- Enhanced performance is obtained by heating (~220 ° C) substrate during MgF2 deposition
- Reflectance > 80% at λ > 115.0 nm



Micro-roughness Al+MgF2 Coatings

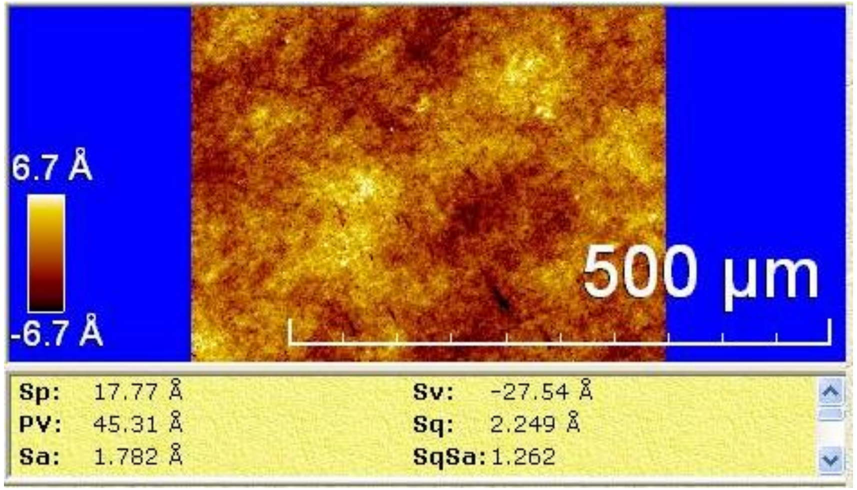
Standard Deposition



Sp: 165.8 Å
PV: 200.1 Å
Sa: 2.336 Å
Sv: -34.24 Å
Sq: 3.027 Å
SqSa: 1.296

AM2 13 01C	x20 mag/ angstroms		
		PV (Å)	Sq (Å)
top left		75.58	6.146
top right		101.2	5.196
center		128	4.021
bottom left		200.1	3.027
bottom right		100	3.282
average		120.97	**4.3344**

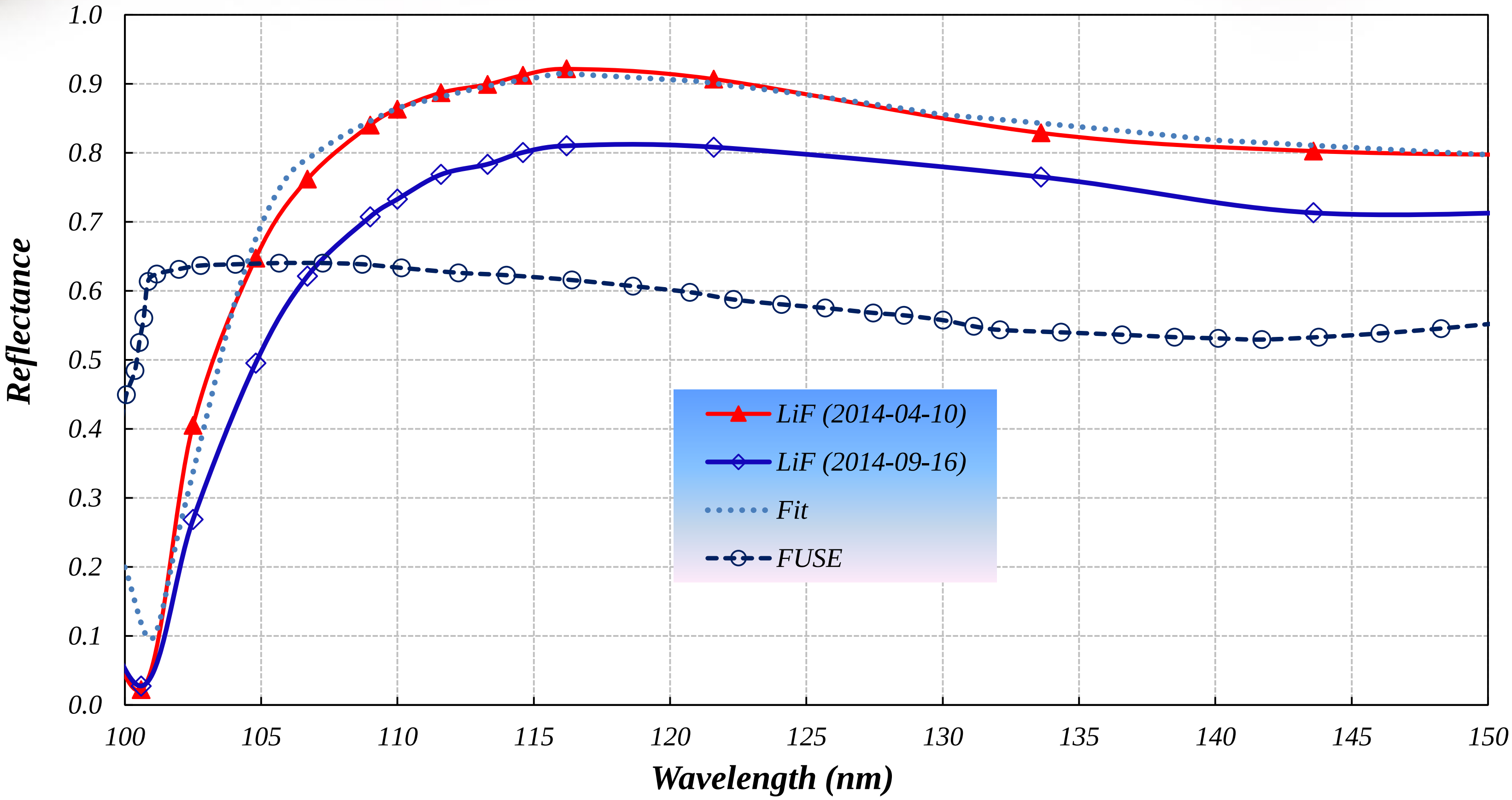
Hot Deposition



Sp: 17.77 Å
PV: 45.31 Å
Sa: 1.782 Å
Sv: -27.54 Å
Sq: 2.249 Å
SqSa: 1.262

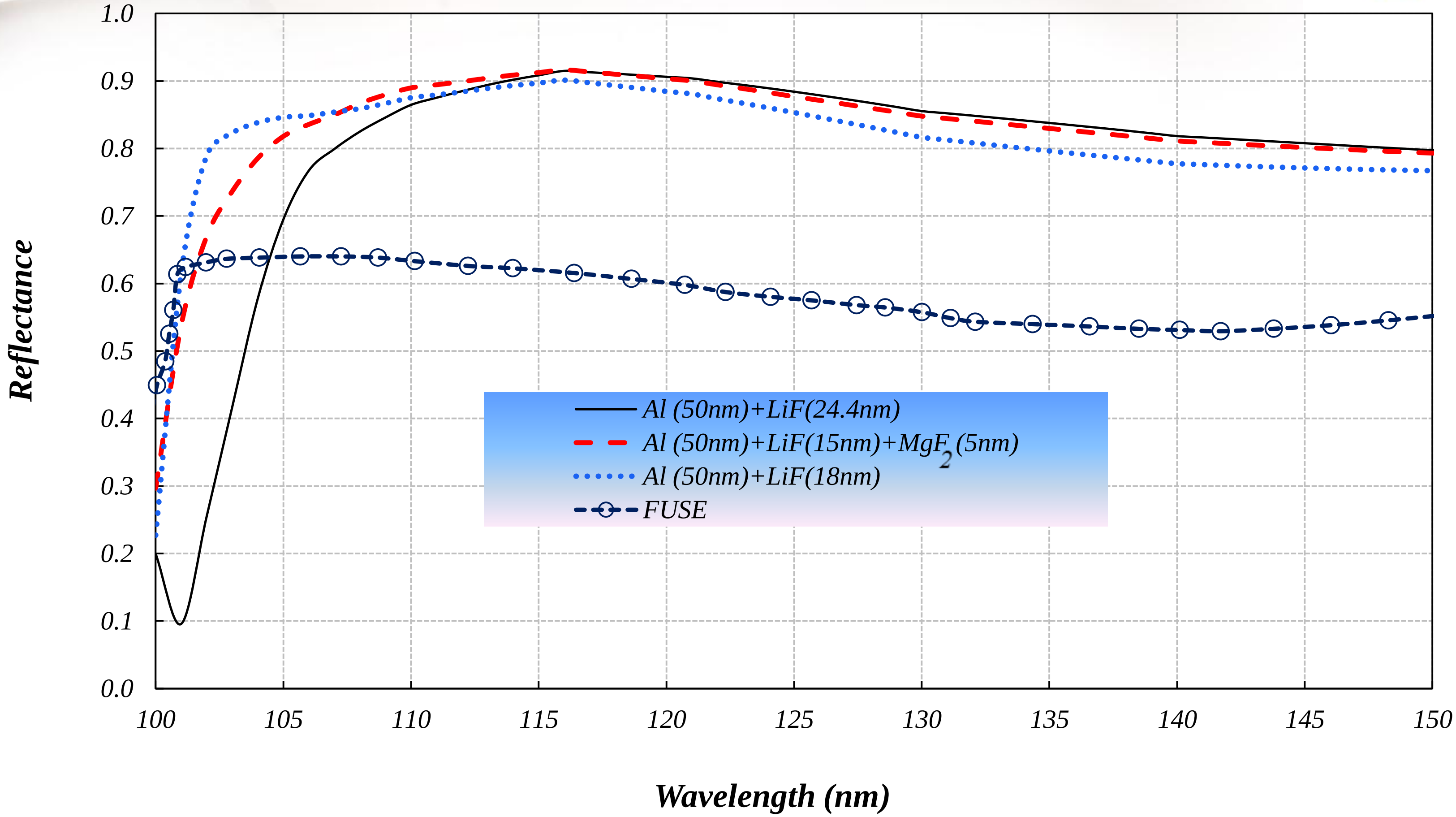
AMCT 13 01A	x20 mag/ angstroms		
		PV (Å)	Sq (Å)
top left		45.31	2.249
top right		40.19	2.331
center		50.96	3.304
bottom left		44.39	2.923
bottom right		50.85	3.854
average		46.34	**2.9322**

Al+LiF Mirror FUV Performance



Coating recipe: Al (43nm, ambient)+LiF(8nm, ambient)+LiF(16.4nm, 250° C)
R_{ave}(100-150nm): 59% (FUSE) 75% (LiF)

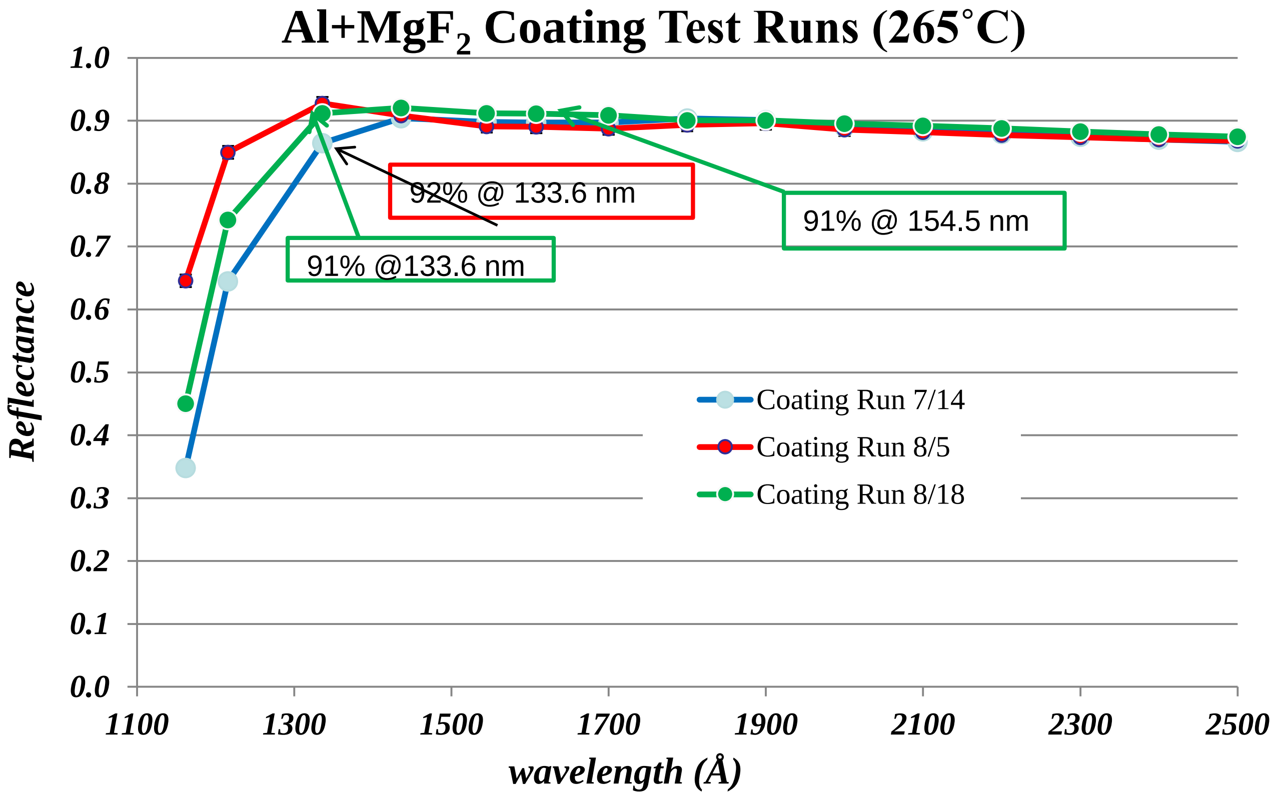
Al+LiF Mirror FUV Predicted Performance



Dual bowl fixture

ICON/GOLD Coating Tasks

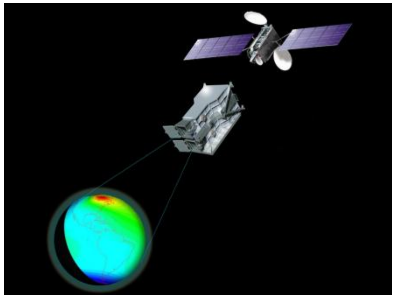
- ICON (Ionospheric Connection explorer): Study Earth's low-orbit ionosphere sun interactions
- GOLD (Global-scale Observations of the Limb and Disk) : Imager to map Earth's thermosphere & ionosphere


Al+MgF$_2$ Coating Test Runs (265˚C)

92% @ 133.6 nm

91% @133.6 nm

91% @ 154.5 nm



- ➢ A total of 12 optics ranging in size from 26 mm to 264 mm
- ➢ Coatings are optimized to produce reflectance over 90% in the 134-156 nm range

Conclusions and Future Plans

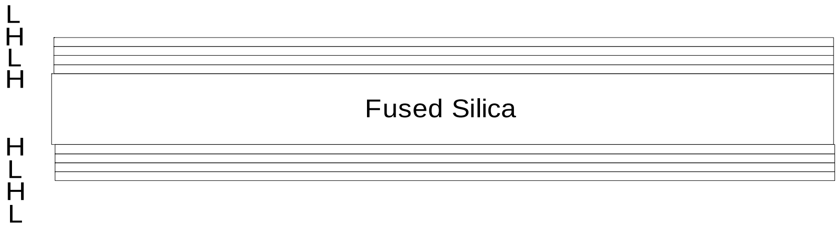
- Reported gains in FUV reflectivity of Al+MgF_2 and Al+LiF mirrors by employing a 3-step process during PVD coating deposition of these materials.
- Successful demonstration of enhancement in FUV reflectance using a large 2-meter chamber.
- Characterization of lanthanide tri-fluoride material candidates to determine their FUV transparency for development of dielectric coatings.
- On-going task of producing Al(50)+LiF(15nm)+MgF_2(5nm).
- Production of FUV reflector and A/R coatings with dielectric (MgF_2/GdF_3) pairs.

Acknowledgement

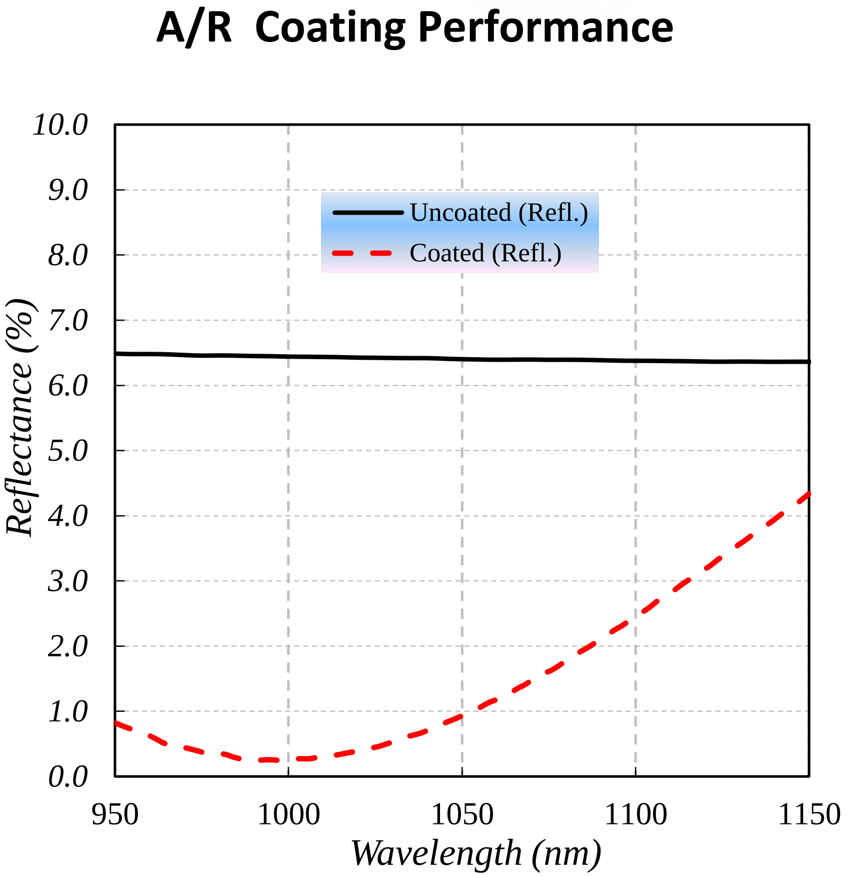
Collaborators: *Javier del Hoyo,*
Steve Rice,
Felix Threat,
Jeffrey Kruk,
Charles Bowers

A/R Coating Example

- A/R to suppress FS reflection losses near 1000 nm
- Design includes 2 layer pairs of GdF_3(H)/MgF_2(L) (181 and 200 nm respectively) on both sides

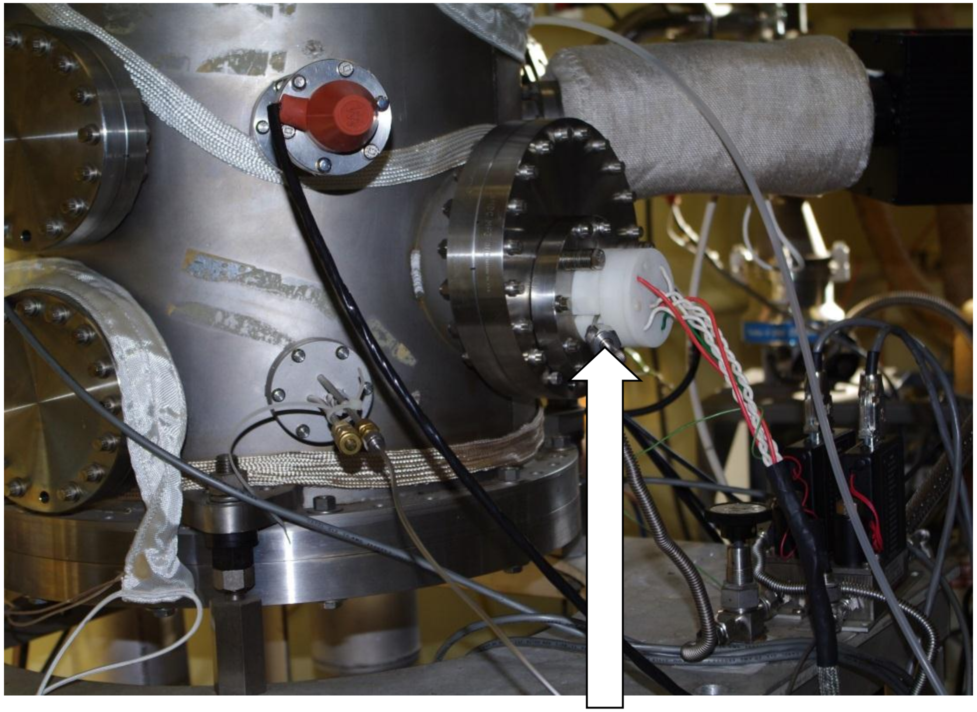


Performance is 0.25% near 1000 nm



Ion Beam Sputtering Coating Chamber

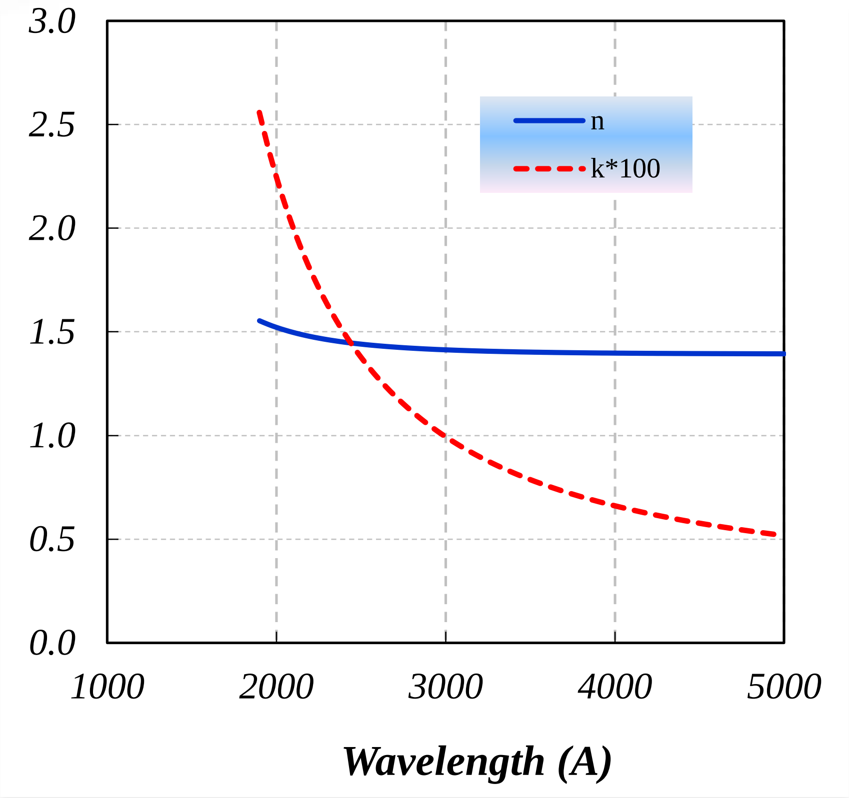
- Upgrade chamber with a two-gas flow controller system.
- Krypton gas to be used in the ion-beam sputtering depositions.
- Freon (CF4) used as reactive gas to replenish the targets (MgF2) stoichiometry.
- Added heaters to the chamber: To improve microcrystalline film properties.



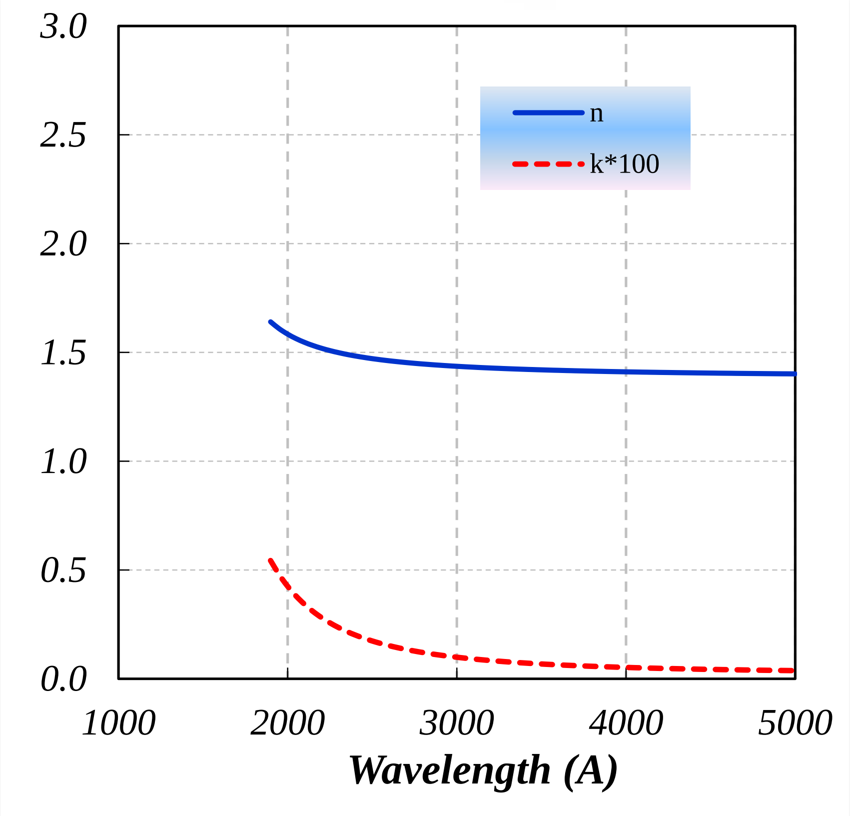
Reactive gas intake

Comparison MgF2 Depositions in IBS Chamber

Normal IBS



Reactive IBS



- Characterization of MgF2 films produced with the IBS process were not as good as conventional PVD results. As a result not coating runs of LiF films using reactive IBS were attempted
- Problem could be traced to at degradation of cathode filament due to reactive fluoride containing gas (Freon) in chamber
- Solution will be to procure an ion gun source without a filament:
  - Cost is over $100k
  - Efforts were not pursued due to budget constraints