FY25 Strategic University Research Partnership (SURP)

# Multilayer Thin Film Coatings for Far Ultraviolet Spectropolarimetry

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***Background:*** The detection of polarized light has brought attraction in astrophysics, solar physics, and planetary science. For instance, *POLLUX* is a high-resolution UV spectropolarimeter designed to study phenomena such as galaxy and star formation, as well as reflected light from exoplanets or stellar magnetospheres. *POLLUX* is capable of operating in both spectropolarimetric and spectroscopic modes, with a particular focus on the far-UV range (90–200 nm). It is evident that emerging demands on UV polarimetric capabilities will need broader development of polarization optics. Hence, we will primarily focus on following the modulator-analyzer scheme used by the *POLLUX*, as shown in Figure 1. Our objective is to develop multilayer coatings of oxides and fluorides for far-UV spectropolarimetry. We aim to (a) design and model the candidate materials to derive the efficiency of polarimetric figure of merit, (b) deposit and characterize the oxide or fluoride multilayers chosen from the designed materials by pulsed laser deposition, and (c) characterize the polarimetric precision of multilayer optics and angular polarization properties by spectroscopy.

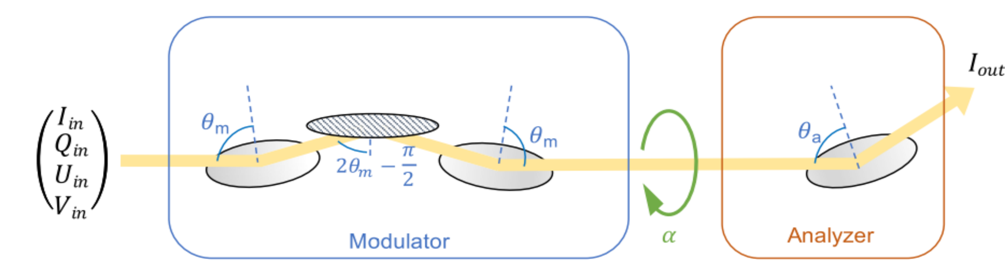



**Figure 1.** Schematic of a reflective polarimeter capable of operating in the FUV.

***Introduction:***

Fresnel Equations

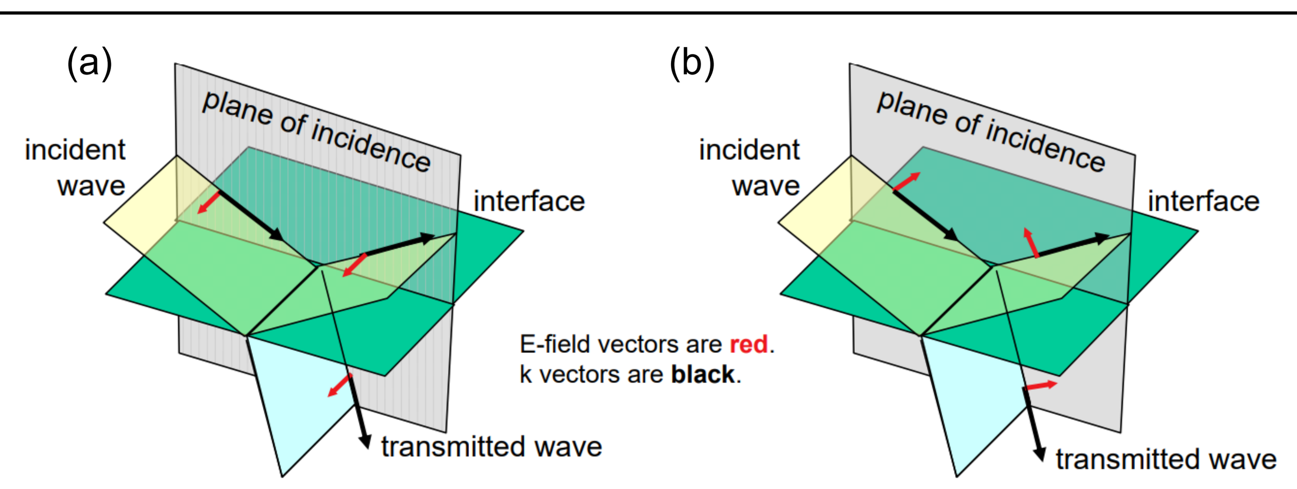



**Figure 2.** Schematic illusion of (a) incident s-polarized light, and (b) incident p-polarized light.

s-polarized light:

$$r_{\perp} = \frac{n_i \cos(\theta_i) - n_t \cos(\theta_t)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

$$t_{\perp} = \frac{2 n_i \cos(\theta_i)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

p-polarized light:

$$r_{\parallel} = \frac{n_t \cos(\theta_i) - n_i \cos(\theta_t)}{n_i \cos(\theta_t) + n_t \cos(\theta_i)}$$

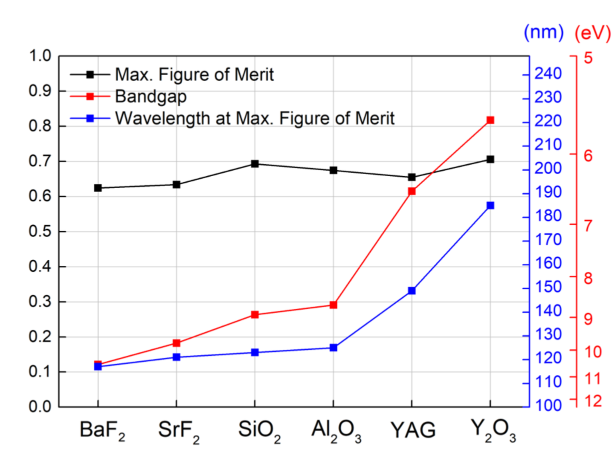
$$t_{\parallel} = \frac{2 n_i \cos(\theta_i)}{n_i \cos(\theta_t) + n_t \cos(\theta_i)}$$

Snell's Law: $n_i \sin(\theta_i) = n_t \sin(\theta_t)$

Polarimetric figure of merit: Quality Factor (κ) $\boldsymbol{\kappa = 2\mu^2 R}$

Throughput: $\boldsymbol{R = \frac{R_s + R_p}{2}}$

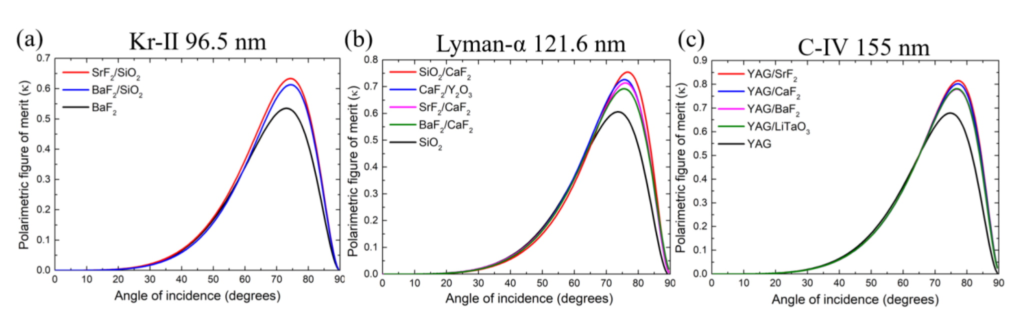
Efficiency: $\boldsymbol{\mu = \frac{R_s - R_p}{R_s + R_p}}$



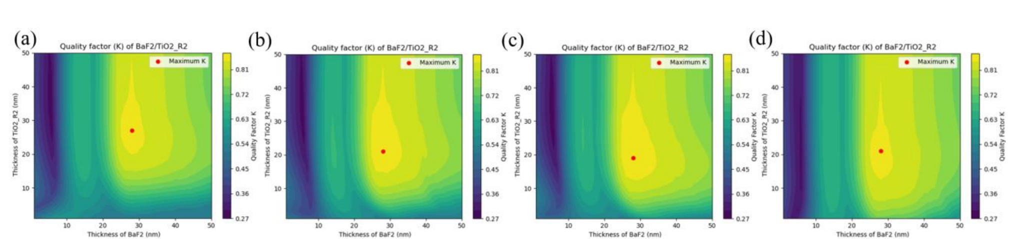

Comparison of maximum polarimetric figure of merit (κ), refractive index, bandgap energy, and the corresponding wavelength at which κ is maximized for various materials.

| Material combination | 1st layer optimal thickness (nm) | 2nd layer optimal thickness (nm) | Max. polarimetric figure of merit (κ) at Kr-II 96.5 nm | Max. polarimetric figure of merit (κ) at Lyman-α 121.6 nm | Max. polarimetric figure of merit (κ) at C-IV 155 nm | Average polarimetric figure of merit (κ) |
|---|---|---|---|---|---|---|
| $SrF_2/SiO_2$ | 17 | 8 | 0.63 | 0.56 | 0.13 | 0.44 |
| $BaF_2/SiO_2$ | 8 | 14 | 0.61 | 0.45 | 0.23 | 0.43 |
| $SiO_2/CaF_2$ | 6 | 20 | 0.33 | 0.75 | 0.11 | 0.40 |
| $CaF_2/Y_2O_3$ | 27 | 14 | 0.37 | 0.71 | 0.03 | 0.37 |
| $SrF_2/CaF_2$ | 9 | 18 | 0.40 | 0.72 | 0.09 | 0.40 |
| $BaF_2/CaF_2$ | 6 | 22 | 0.59 | 0.69 | 0.10 | 0.46 |
| $YAG/SrF_2$ | 13 | 36 | 0.34 | 0.46 | 0.82 | 0.54 |
| $YAG/CaF_2$ | 13 | 34 | 0.31 | 0.46 | 0.80 | 0.52 |
| $YAG/BaF_2$ | 13 | 31 | 0.30 | 0.46 | 0.78 | 0.51 |
| $YAG/LiTaO_3$ | 14 | 36 | 0.31 | 0.48 | 0.78 | 0.52 |

Summary of optimal thicknesses and the maximum polarimetric figure of merit (κ) for bilayer coatings composed of various oxides and fluorides on Al2O3 substrates at key far ultraviolet (FUV) wavelengths—Kr-II (96.5 nm), Lyman-α (121.6 nm), and C-IV (155 nm)— under s- and p-polarized light at optimal incidence angles.




Polarimetric figure of merit (κ) for single-layer and bilayer configurations plotted as a function of incidence angle at selected wavelengths: (a) 96.5 nm (Kr-II line), (b) 121.6 nm (Lyman-α line), and (c) 155 nm (C-IV line). Bilayer coatings significantly enhance polarimetric performance via engineered interference.

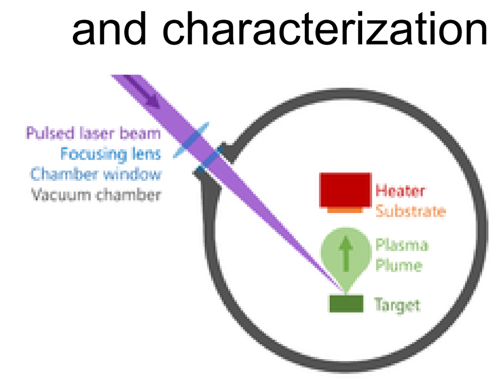



Layer thickness optimization for bilayer BaF2/TiO2 to maximize the polarimetric figure of merit on various (a) CaF2, (b) SiO2, (c) sapphire (Al2O3) and (d) SrTiO3 substrates. The red dot identifies the optimal thickness configuration for maximizing κ.

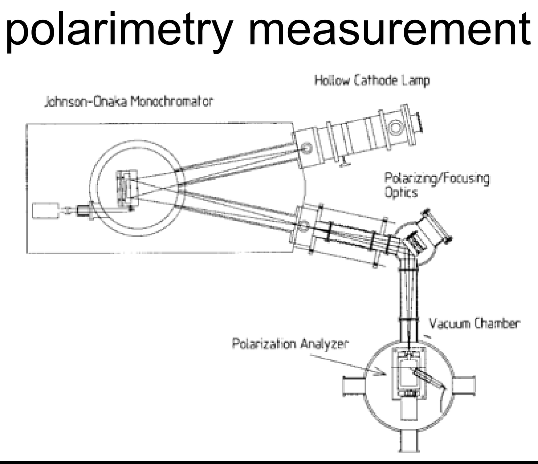
***Summary:*** We have developed modelling the polarimetric figure of merit (κ) of single layer and bi-layers of oxides, sulfides and fluorides on sapphire ($Al_2O_3$) substrate at the wavelength ranging from 120-150 nm and have optimized the maximum of the polarimetric figure of merit (κ) by varying the thickness of designed materials (one-layer or multilayer) and the incident angle to the single or multilayer. We show that multilayer allows us to achieve higher figure of merit.

***Ongoing Work:***

Pulsed laser deposition growth and characterization




Experimental setup for VUV polarimetry measurement




***Significance/Benefits to JPL and NASA:*** This is a natural enhancement to ongoing JPL efforts in UV spectroscopy and is supported by extensive experience in UV materials and characterization work at JPL. The long-term benefits of this program could lead to new FUV instrumentation that leverages existing JPL UV technologies in detector systems, optical coatings, and diffraction gratings.

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