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Sophisticated band pass filters and dichroic by PARMS technology for the LSTM project

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ABSTRACT

The Copernicus Land Surface Temperature Monitoring (LSTM) mission is part of the Copernicus Sentinel Expansion Missions. It will carry a high spatial-temporal resolution thermal infrared sensor to provide observations of the land-surface temperature. The mission responds to priority requirements of the agricultural user community for improving sustainable monitoring requirements to better manage water resources and learn about yield, vegetation and crop growth. The spectral coverage in the multiple bands spans from 490nm to 1610nm for the VNIR/SWIR part of the instrument. Materion Optics Balzers was selected as responsible supplier for the VNIR/SWIR filter assemblies. This contribution addresses the design, manufacturing and characterization of the demanding dielectric optical coatings for the sophisticated band pass filters and dichroic by PARMS technology for the LSTM project by Materion Optics Balzers.

Keywords: coating, PARMS, VIS, NIR, bandpass, evaporation, sputtering, LSTM instrument

1. INTRODUCTION

The Copernicus Land Surface Temperature Monitoring (LSTM) mission will carry a high spatial-temporal resolution thermal infrared sensor to provide observations of the land-surface temperature. The mission responds to priority requirements of the agricultural user community for improving sustainable monitoring requirements to better manage water resources and learn about yield, vegetation and crop growth.

The LSTM observations are made in 6 spectral channels in the VNIR-SWIR spectral range as well as 5 TIR spectral bands (see Table 1). The VNIR-SWIR path splits into 2 paths by a dichroic beam-splitter. The first path is the NIR-SWIR focal plane with NIR-SWIR filters and detector on dichroic-2 transmitted path and second, the VIS focal plane with VIS filters and detector on dichroic beam-splitter-2 reflected path. The bandpass is shaped by a first stage of filtering (acronym IPF). The background is rejected, and the crosstalk is minimized thanks to a second stage of filtering (acronym DPF). On VNIR-SWIR paths, the first common stage is with IPF-VNIR filters located close to the dichroic, while the filtering is completed with DPF-NIR and DPF-VIS, respectively.

Each mounted filter unit includes stripe filters dedicated to several spectral VNIR and SWIR. The IPF units are large stripe filters and a wedged lens element operating under low incidence angles and with high F-number beams. The DPF units are smaller stripe filters operating under a wide range of incidence angles and with low F-number beams.

The LSTM satellite is designed and build by Airbus DS in Madrid, while the development and production of the advanced technology instrument is carried out by Airbus DS in Toulouse. The detector plane filters (DPF) for the SWIR and VIS detector, the intermediate plane filters VNIR (IPF-VNIR), the IPF lens and the dichroic plate are developed and manufactured by Materion Balzers Optics (MBO). MBO is also the responsible supplier for the VNIR/SWIR filter assemblies.

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In this presentation, we address the design, manufacturing and characterization of the demanding dielectric optical coatings for the sophisticated band-pass filter (BPF) stripes and the dichroic developed by Materion Balzers Optics [1]. In the case of the IPF SWIR, the coatings are up to 25µm thick on each side. The optical thin film layers are deposited by Plasma-Assisted Reactive Magnetron Sputtering (PARMS) and cover the spectral range for the central wavelength from 490nm to 1610nm with a bandwidth ranging between 20 and 90nm. The outstanding optical performance of the optical components is ensured by the combination of the PARMS technology with a state-of-the-art optical broad-band monitoring system (BBM) which allows in-situ process control and in-situ correction. The overall optical performance is achieved by distributing the optical design among the 4 included surfaces – 2 for the dichroic and 2 for the BPFs. We show very steep dichroic edge performance, due to narrow transition from reflectance to high transmittance. There is a very low angular shift of the dichroic edge for several challenging illumination scenarios. The BPFs exhibit very broad out-of-band blocking down to OD6.

2. LSTM FILTER STRIPE ASSEMBLY APPROACH

The manufacturing of the LSTM filter arrays is based on the concept of the integration of single filter stripes into a mechanical frame. This requires besides the manufacturing of filter stripes also the development and manufacturing of a sophisticated mechanical frame. This approach was used for Sentinel 2 MSI [2,3,4] and is subcontracted in the LSTM project to Fraunhofer Institute for Applied Optics and Precision Engineering in Jena, Germany.
Single filter elements for the detector plane filters (DPF) and intermediate plane filters (IPF) are be arranged into mechanical subassemblies made of titanium alloys and are aligned into the optical instrument in front of the detectors. During the integration of the single filter elements to filter arrays, the optical elements are arranged into the mechanical holders with positioning accuracies in the order of up to 10 µm. Metallic foils with a black coating are inserted in between the single filter stripes in order to avoid cross talk. The filter stripes are covered by a frame with optical apertures.

The deposition of the BPFs is performed on Ø100 mm fused silica wafers followed by dicing. The dicing of the stripes is carried out with a DISCO chip saw DAD 3650. Figure 1 shows the schematic layout of the LSTM DPF-SWIR filter stripes on the wafer (left in blue) and a microscopy image of a diced BPF stripe (right), respectively. The picture shows the smooth dicing edges with chipping well below 10µm and a typical 50µm protection chamfer.

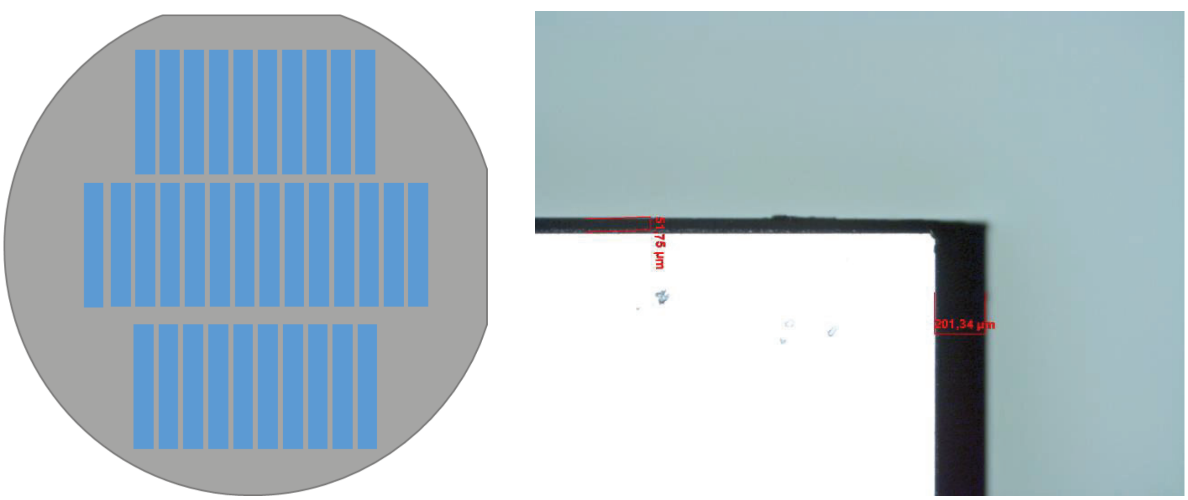

Figure 1: Left: schematic layout of LSTM DPF-SWIR filters (blue bars) diced from Ø100mm fused silica wafer. Right: microscopy image of the edge of a single LSTM BPF after dicing with chipping below 10µm.

3. OPTICAL DESIGN AND MANUFACTURING APPROACH

This chapter briefly describes the driving requirements for the LSTM BPF and dichroic design and production approach.

Table 1. LSTM Spectral Channels

	Channel	Central wavelength λc [µm]	FWHM [µm]
VNIR	VNIR-0	0.490	0.065
	VNIR-1	0.665	0.03
	VNIR-2	0.865	0.02
	VNIR-3 a/b	0.945	0.02
SWIR	SWIR-1	1.38	0.03
	SWIR-2	1.61	0.09
TIR	TIR-1	8.6	0.18
	TIR-2	8.9	0.18
	TIR-3	9.2	0.18
	TIR-4	10.9	0.40
	TIR-5	12.0	0.47

3.1 Deposition of multi-layer systems

The coatings of the LSTM optical elements are performed by means of state-of-the-art Plasma-Assisted Reactive Magnetron Sputtering (PARMS) [5, 6]. All PARMS plants at MBO-J are equipped with a sophisticated optical broad-band monitoring system (BBM) that allows the measuring of the optical thickness of the growing thin films directly on the rotating substrate holder with an approximated accuracy of 0.5nm as minimum [5].

During the earlier Sentinel 2 project a study regarding PARMS suitability had been conducted. It could be shown that applied to complex self-blocking BPF the PARMS process is superior to the IAD (ion-assisted deposition) process in terms of spectral performance, uniformity, process stability, scattering performance and surface roughness. The PARMS process revealed an excellent ability to reproduce the surface quality of the substrate.

MBO-J uses its Helios plants (Helios 500 and 800 by Bühler) to perform the optical coatings for the LSTM project. As substrates for the BP Filters and dichroic Corning Fused Silica (HPFS 7979 0F) is used. The BPF operate in the spectral channels reported in Table 1.

3.2 Optical design approach

The instrument set-up allows for distributing spectral properties onto the different optical components within the optical path. The spectral transmittance form of the BPF is essentially given by the Intermediate Plane Filters (IPF), whereas the blocking function is finalized by the Blocking Filters (BKF), which are the Detector Plane Filters (DPF). For each channel individual blocking levels in the order of optical density 4 to 5 are required.

Also, every filter surface pair must consider a slightly different angular distribution of incidence angles. Smallest possible angles fit to the position of the DPF, which reduce the angular shift inherent to the interference coatings, shaping the band pass. It is this angular shift which extends the filter edge steepness to fit into the specified spectral template (see Figure 2), that is driving the overall thin film layer thickness, and number of layers, of the BPF side providing the BPF shape. In case of the SWIR1-channel this sums up to 25µm. The combined blocking behavior can be realized with a lower amount of filter thickness applied to the other surfaces, being a compromise of ensured spectral performance as outcome and a robust thin-film-design, which is not too sensitive to thickness-errors.

The 7 BP filters operating in the VNIR and SWIR spectral range are characterized by high constant transmittance in the pass region and broad blocking regions, comprising low levels of scattering. This requires a high-energetic deposition process and excellent thin-film growth control in the region of few Å (angstrom). The Plasma Assisted Reactive Magnetron Sputtering (PARMS) process with Broad Band Monitoring (BBM) is an adequate technological approach here.

Additional criteria, which drive the overall thickness of a BPF coating, are the slope requirement and the rejection ratio, which defines the absolute level of the transmittance in the Out-of-Band spectral range. Furthermore, the requirements for low In- and Out-of-Band scattering into the forward direction of incoming light influences the thin-film design itself, the concept of coating combination and filter orientation as well as the choice of coating materials.

MBOs realized the requested spectral performance with a certain optimum number of layers to be coated and minimal total thickness of the coatings.

This was motivated by:

- the general manufacturing process risk,
- allowing for a good controllability of manufacturing,
- low production tolerances during the manufacturing process,
- contamination risk during long lasting coating processes and
- the long-term environmental stability of the component(s).

From MBOs practical experience in maintaining opto-mechanical properties at a reasonable level demonstrated in the past, a restriction of the total thickness to about 30µm of a single coating was targeted. It evolved that the realization of such coatings – especially with the required homogeneity – depends on a stable and extremely deterministic deposition process. The individual layers are allowed to comprise an absolute error-level of few angstroms only. Each BP filter design calculation is based on the AOI histogram data in order to achieve the overall subsystem performance.

3.3 Spectral performance of optical design

Figure 2 shows the VNIR-2 combined spectral response function of the design IPF unit together with the DPF design. 3 different field of view scenarios are shown in yellow, blue and grey, respectively. The combined blocking is depicted in **Figure 3**. The black curve shows the target blocking. As described in 3.2 this superior BPF shape blocking of down to OD6 is achieved by the distribution of the thin film layer stacks onto the available surfaces of the IPF stripes, dichroic and DPF stripes.

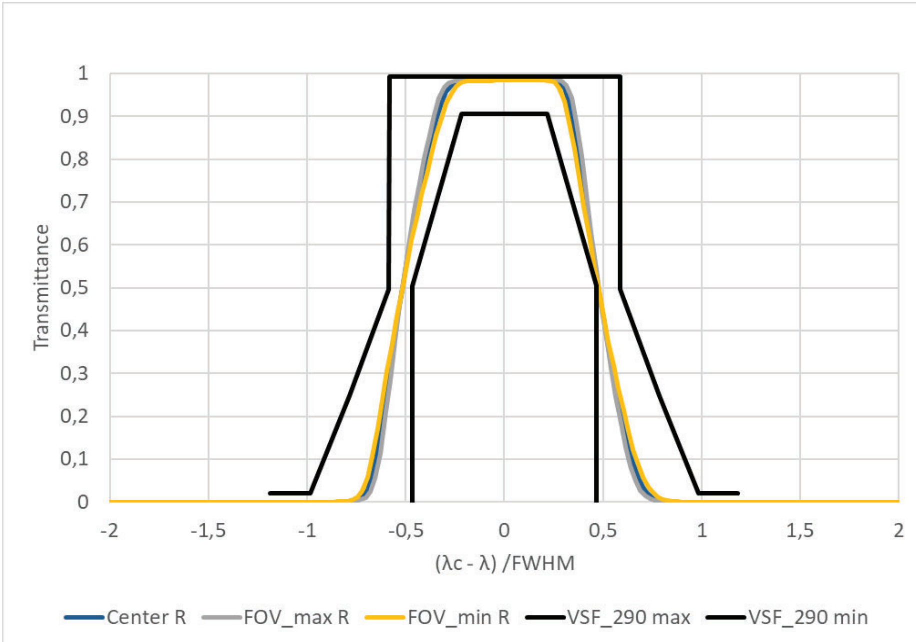

Figure 2: VNIR-2 performance analysis (design), black line, spectral shape target

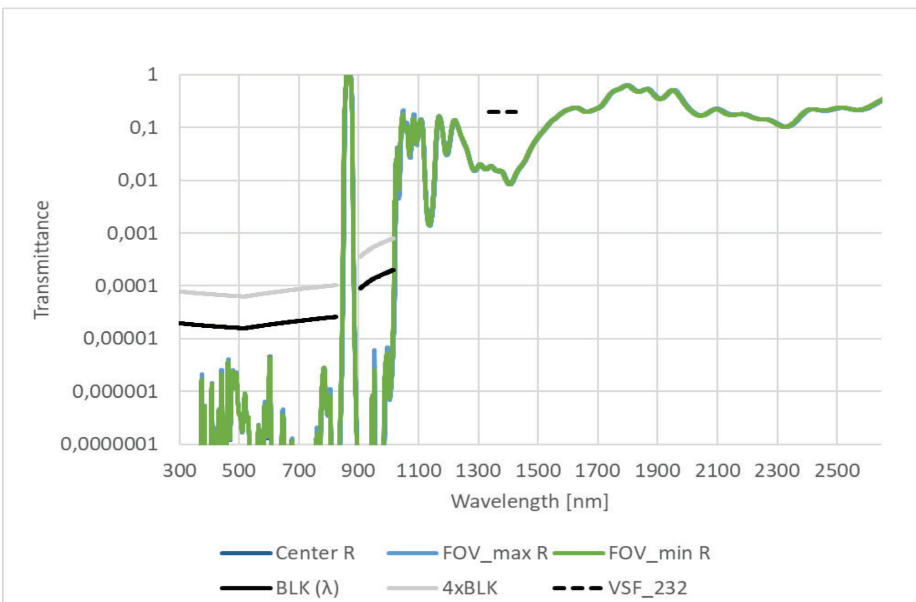

Figure 3: VNIR-2 SWIR combined blocking (optical design); black/grey curves, field of view scenarios are shown (blue, green)

4. SPECTRAL CHARACTERIZATION OF LSTM BP FILTERS

This section contains a spectral characterization of the LSTM BPFs and dichroic.

4.1 Transmission and block measurements

The spectral characterization of the BP filters was done using spectrometers Perkin Elmer Lambda 950/1050, which are double beam, double monochromator, ratio recording UV/Vis/NIR spectrophotometers.

Figure 4 shows the measured transmission spectral of the IPF VNIR-2 BPF as a typical example for the LSTM bandpass filters. The averaged measured FWHM is 19.9nm with the average transmission level in the bandpass region is 99%. The specific designs were chosen to fulfil a pre-defined IPF stripe + IPF lens + DPF stripe spectral shape templates (see example in Figure 5). The figure shows the IPF VNIR-2 BPF (measurement uncertainty is given by horizontal bars) combined with the design performance of the IPF lens and DPF stripes. Main-drivers for the complexity, i.e. number of layers and also the total thickness of the required coatings were the width and depth of the spectral blocking range, the slopes of the bandpass-edges and the In-Band Equivalent Transmittance/Reflectance while partly being related.

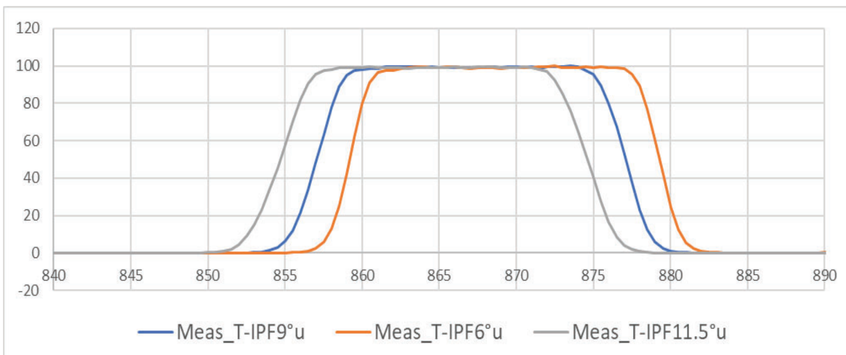

Figure 4: Measured IPF VNRI-2 BPF spectral performance at 3 several AOIs.

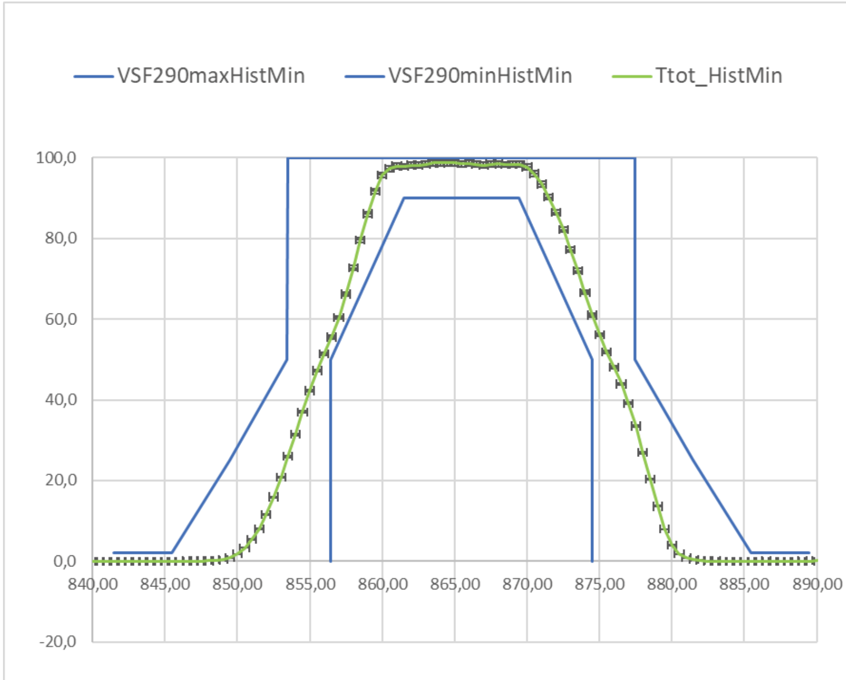

Figure 5: Combined IPF VNIR-2 stripe (measurement) + IPF lens (design) + DPF stripe (design) results. Y-scale: non-normalized SRF

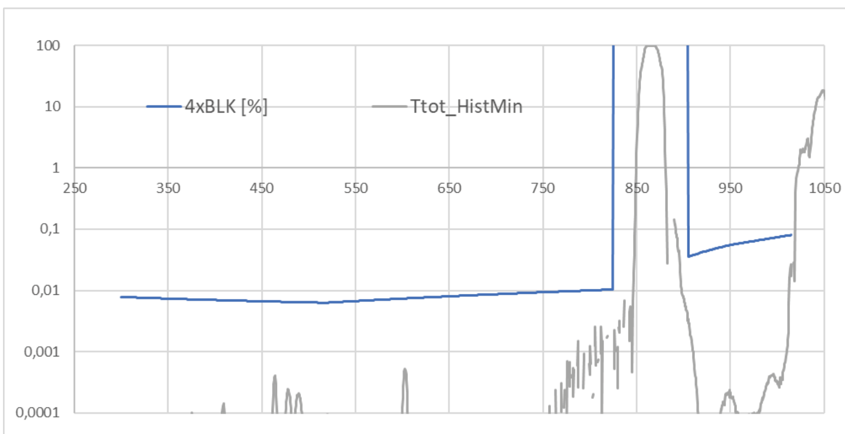

Figure 6: Combined blocking IPF VNIR-2 stripe (measurement) + IPF lens (design) + DPF stripe (design) results; blue: blocking target; grey: measurement

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5. DICHROIC DEPOSITION AND SPECTRAL CHARACTERIZATION

The deposition of the LSTM dichroic is also done by means of the PARMS technology described in 3.1.
Different FOV scenarios (FOV max, FOV, min and center) are considered in the calculation and production of the dichroic and BPFs together. An overall analysis combines the FOV scenarios (AOIs) with different homogeneity scenarios. This ensures the desired spectral system performance.

The conception and detailed design of the dichroic was done during the pre-design phase of LSTM. The main technological characteristics of the design and coating approach are listed hereafter:
- Coating technology: PARMS coating (Helios 800)
- Coating material: Nb_2O_5/SiO_2
- Coating thickness: 14.8 µm
- Substrate material: Fused Silica (Corning 7979)
- Number of Layers: 176.

Figure 7 and Figure 8 show the measured reflectance and transmittance performance of the dichroic from the LSTM pre-development. The results at the AOIs 8°, 22° and 36° of the dichroic with corresponding requirement levels from the pre-design project phase and design data (dotted lines) are depicted together with the s-, p- and randomly polarized light scenarios. The spectral position of the six channels of the BPFs are indicated by the black/grey curves.

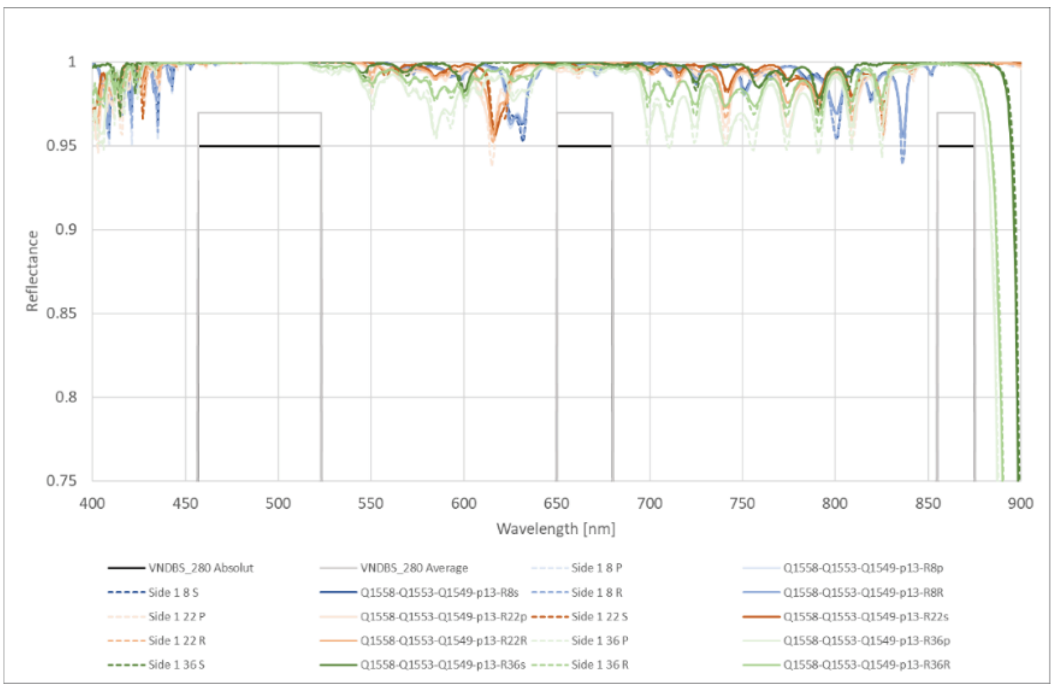

Figure 7: Reflectance measurement data (straight lines) at the AOIs 8°, 22° and 36° of the dichroic with corresponding requirement levels from the pre-design project phase and design data (dotted lines). Detailed view. S-, p- and randomly polarized light scenarios are shown for each AOI.

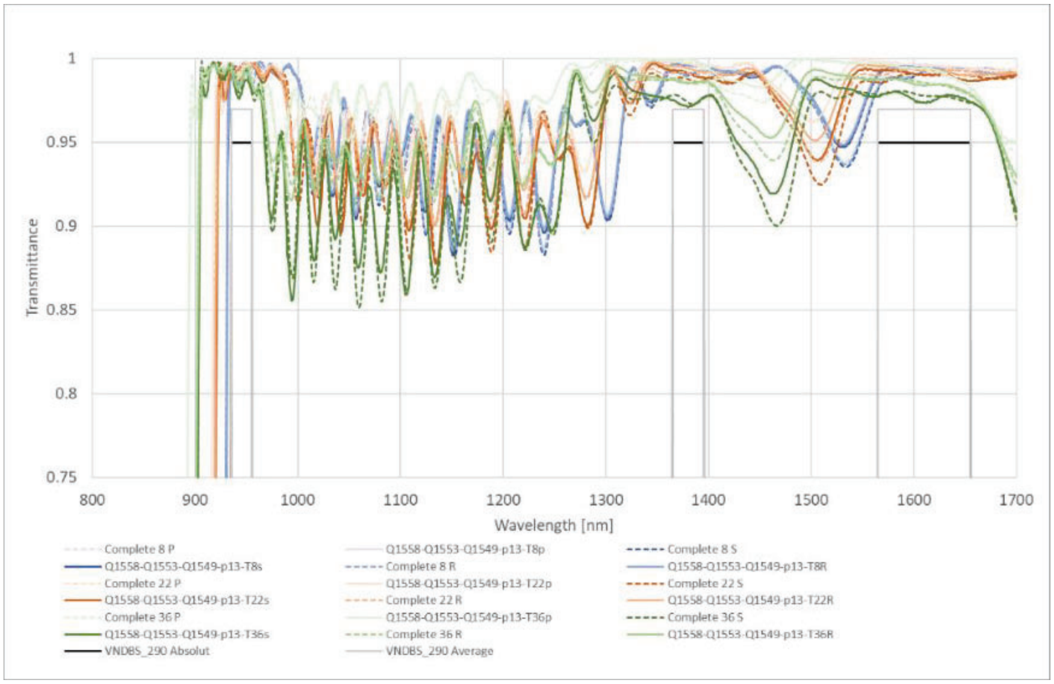

Figure 8: Transmittance measurement data (straight colored lines) at the AOIs 8°, 22° and 36° of the dichroic with corresponding requirement levels and design data (dotted lines). Detailed view. S-, p- and randomly polarized light scenarios are shown for each AOI.

6. CONCLUSION

We presented the optical design concept for the dichroic and VNIR/SWIR band pass filters for the LSTM project. The manufacturing approach of the LSTM BPFs was discussed in detail. The optical thin films deposited by the PARMS method show outstanding optical performance with typical transmission levels of 99%. The first spectral results of produced VNIR-2 filters were shown. The combined IPF VNIR-2 stripe (measurement), IPF lens (design), DPF stripe transmission and blocking curves were shown. These results resemble the expected optical design curves very closely. A out-of band blocking over a wide range down to OD6 was presented. Preliminary dichroic results show very steep dichroic edge performance, due to narrow transition from reflectance to high transmittance.

ACKNOWLEDGEMENTS

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