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Development of linear variable filters and black coatings by PARMS technology for FLORIS HR focal plane array of FLEX mission

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ABSTRACT

Beside homogeneous filter coatings a coating can also be applied with a linear gradient. Linear gradient or linear variable filters show a gradient of a band edge or central wavelength depending on the filter type in spectral direction and they are homogeneous in spatial direction. In this paper, we present a linear variable narrow band pass filter with full width half maximum of about 8 nm and a transmittance of more than 98% in the wavelength range of 670 nm to 780 nm. The target for the gradient is 3.3. nm/mm. Due to the need of transmittance filter and AR coating are manufactured by means of Plasma Enhanced Magnetron Sputtering (PARMS). Additionally, the linear variable filter for FLEX mission requires a black mask to separate between HR1 and HR2 channel. This mask is also applied by OBJ by means of the PARMS process and a Ti based layer stack. Here, a reflectance of < 1.5% in the range of 400 nm to 800 nm can be demonstrated. The definition of black mask was done by means of photolithography.

Keywords: coating design, gradient filter, plasma assisted reactive magnetron sputtering, black coating

1. INTRODUCTION

FLORIS (FLuorescence Imaging Spectrometer) is the single High-Resolution Spectrometer instrument of the FLEX (FLuorescence EXplorer) mission, currently under development by the European Space Agency as the eight Earth Explorer Mission [1,2]. The goal of the mission is the monitoring of the chlorophyll fluorescence of plants giving information about their photosynthetic activity. The FLORIS instrument is equipped with two imaging spectrometers. One with high spectral resolution (HR) to measure the fluorescence spectrum and a second spectrometer with lower spectral resolution (LR) to gain further information about vegetation. The focal plane assembly (FPA) of the HR spectrometer is placed in front of two identical matrix detectors called HR1 and HR2 being illuminated with different wavelength ranges. Part of the FPA is a linear variable filter (LVF) in front of the optically relevant area of the HR1 and HR2 detectors. The spectral range of the LVF is between 670 nm and 780 nm. As both detectors are geometrically separated, the area around and between the detector active areas need to be masked by an absorbing black coating. To achieve the required geometrical accuracy of a masking photolithography is necessary. Optics Balzers Jena GmbH (OBJ) was selected by Leonardo and ESA to develop such a component in the framework of a pre-development.
The LVF is specified as narrow band pass filter with a full width half maximum (FWHM) of less than 10 nm (goal 5 nm) and a minimum transmittance in the pass band of more than 98.5%. The central wavelength (CWL) has a gradient along the spectral direction were the gradient is about 3.3 nm/mm. The deposition of such kind of filter coatings alone exceeds the capabilities of well-known ion assisted deposition (IAD) techniques due to transmission loss caused by surface roughness. IAD technology is commonly used for manufacturing of graded coatings. To overcome these limitations plasma assisted reactive magnetron sputtering (PARMS) enables the manufacturing of narrow band pass filters with high transmittance. In this paper the deposition of LVF by means of PARMS technology in line with stringent transmittance requirements was demonstrated. Furthermore, it is demonstrated that PARMS technology shows a better homogeneity of the LVF in spatial direction which is also known as smile.
Beside the LVF coating an absorbing black coating is required. For this purpose, OBJ has developed a process based on titan as metallic material. Recently, beside the spectral performance also the environmental space qualification was demonstrated by OBJ.

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2. DESIGN AND MANUFACTURING APPROACH

The LVF should be a narrow band pass filter inside a template with 10 nm width and a transmittance area of 4.2 nm centered in the template. Consequently, the FWHM of the filter is about 8 nm. The blocking range is defined from 650 nm to 800 nm (< 1% transmittance).
The coating design of the narrow band pass filter is based on a silica (SiO2) and Niobia (Nb5O2) multi-layer stack with 53 layers and a total coating thickness of 7 µm. The corresponding AR coating is composed of the same materials with 4 layers. The width of AR range covers the rang of the gradient (670 nm – 780 nm). The blocking range of the coating is designed in a way that the full blocking width (650 nm to 800 nm) is achieved at the right and left-hand side of the band pass due to the possible shift. The linear gradient is achieved by scaling the total coating thickness along the spectral direction. It must be considered that the scaling of the total thickness has an impact on FWHM of the filter.

The need of a band pass filter with more than 98% transmittance requires the use of PARMS technology. In a previous study with ESA it was found that the transmittance of band pass filters can increased by the use of PARMS technology compared to ion assisted deposition (IAD) due to the lower intrinsic coating roughness [3,4]. Below, the result of a band pass coating in the spectral range of FLEX LVF, filter B6 from Sentinel 2, with IAD and PARMS technology are reported for comparison. PARMS technology has proved its suitability for coating of complex filters also in various applications such as beam splitters [5,6] or notch filters [7].

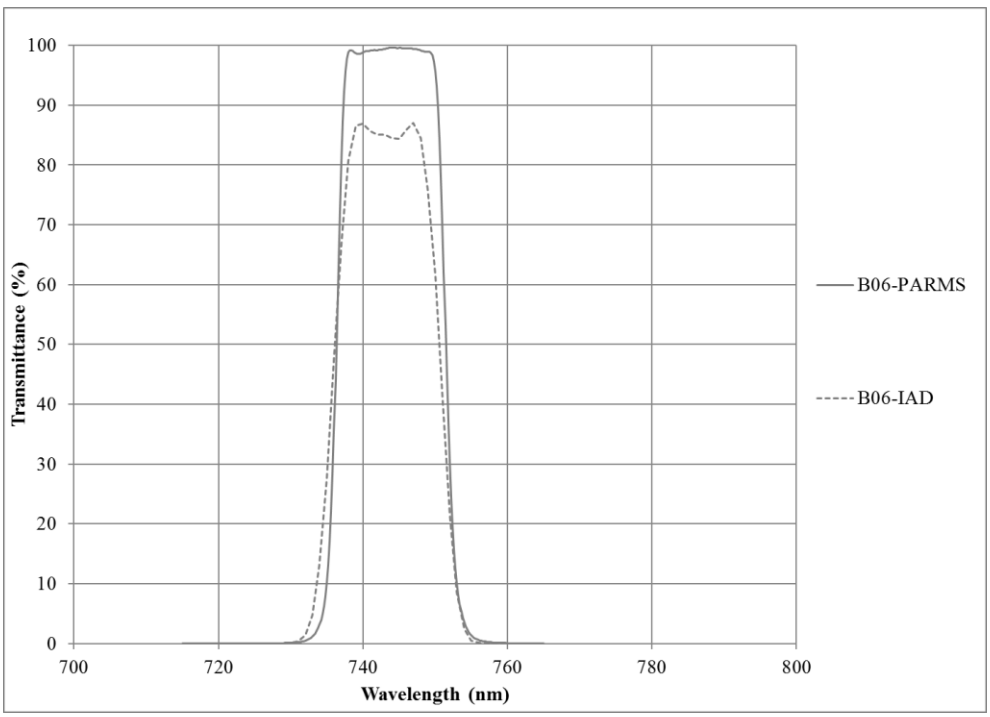

Figure 1. Measured transmittance of S2 filter B6 manufactured by IAD and PARMS technology.

It can be seen that the transmittance of this significantly thicker band pass filter by IAD technology is limited to about 85% while a PARMS coating can achieve a transmittance up to 99%. So, for FLEX mission it is mandatory to use the PARMS process for filter coating.
Usually, LVF are manufactured by IAD process like developments in the framework of Sentinel 5 project. For FLEX LVF it was necessary to develop a coating with linear gradient by means of PARMS process. The gradient was achieved by dedicated mechanical tooling inside the coating chamber.

For the black coating a reflectivity of < 2% is required. The layer stack proposed by OBJ has a total thickness of 0.5 µm with 9 layers.
In the manufacturing flow first LVF and AR coating will be deposited before the LVF face will be structured by means of photolithography with following black coating.

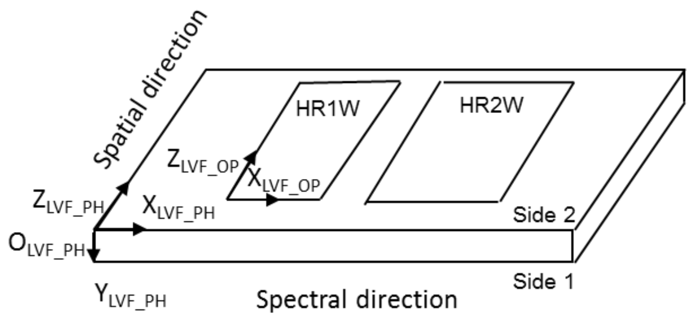

Figure 2. LVF design: Side 1(AR coating+ glue pads), Side 2 LVF+ black coating

So, Side 2 will be coated with the LVF coating on full face. After filter deposition, a black coating will be applied to separate the two spectral windows (HR1W and HR2W). The mask will be applied by means of photolithography. Side 1 will be coated with AR coating with a mechanical mask avoiding coating on the positions of glue pads. The dimensions of the LVF filter windows (HR1W and HR2W) are reported below with the reference to the corresponding spectral range (Table 1):

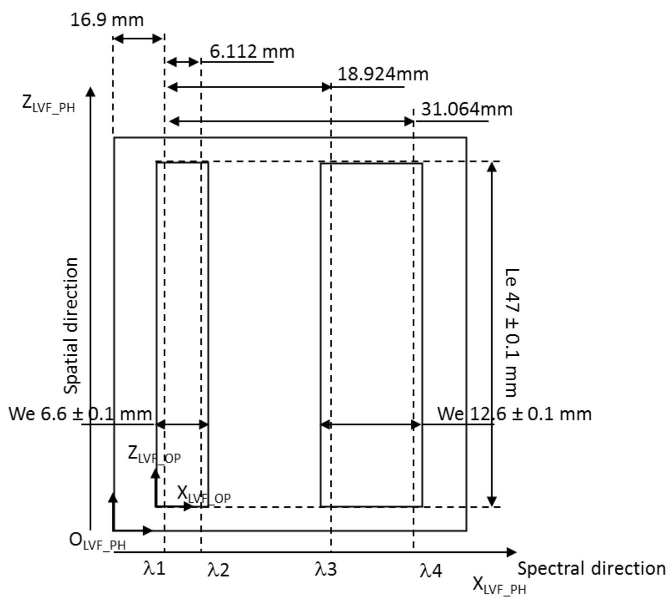

Figure 3. LVF design: HR1W and HRW2 dimensioning

Table 1. LVF design: HR1W and HRW2 spectral range

Coated window	LVF reference wavelength	Value
HR1W	λ1	676.673nm
	λ2	697.019nm
HR2W	λ3	739.673nm
	λ4	780.085nm

3. LVF COATING BY PARMS

Before starting the coating process, it is necessary to adapt the tooling inside the coating chamber in a away that a coating system which usually manufactures homogeneous coating profiles applies a coating with predicted linear gradient. For coating application, a Helios 400 coating system from Bühler equipped with an optical broad-band monitoring (BBM) system is used [8,9]. To check the global gradient distribution inside the coating chamber OBJ has coated a Ø125 mm wafer. The wafer was then characterized with a spectrometer with automated x-y-stage. This allows the measurement of a spectrum for a pre-defined grid. In this case a line along spectral direction. The figure below shows the measured linear gradient with starting saturation on the right-hand side.

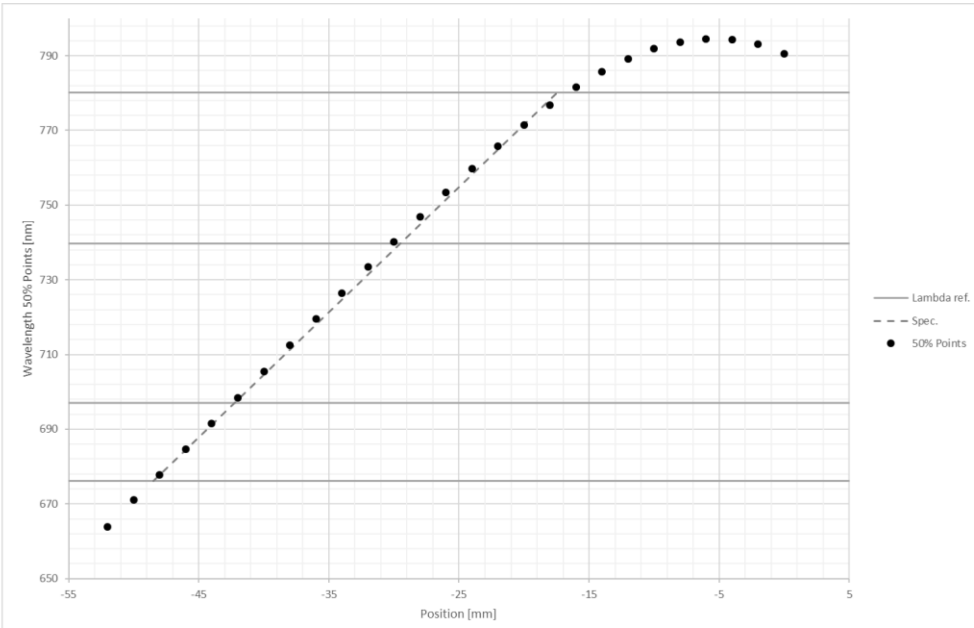

Figure 4. Measured 50% points of manufactured LVF versus requirements.

It can be seen that the measured gradient is in good agreement with the specified one (dotted line). The horizontal lines indicate the windows where the gradient is defined for HR1 and HR2 detector.

The spectral measurements along the spectral direction can be found in the next figure. Measurements were done each 2 mm. It can be seen that the transmittance level at all measurement positions reaches 98%. When looking into detail it is obvious that the FWHM of the single filters increases with increasing wavelength. This is caused by the scaling of the filter. Design wavelength of the filter is 700 nm. For smaller wavelengths the FWHM will decrease while the FWHM increases for longer wavelengths. Within the limits of the specification the maximum FWHM is 10 nm.

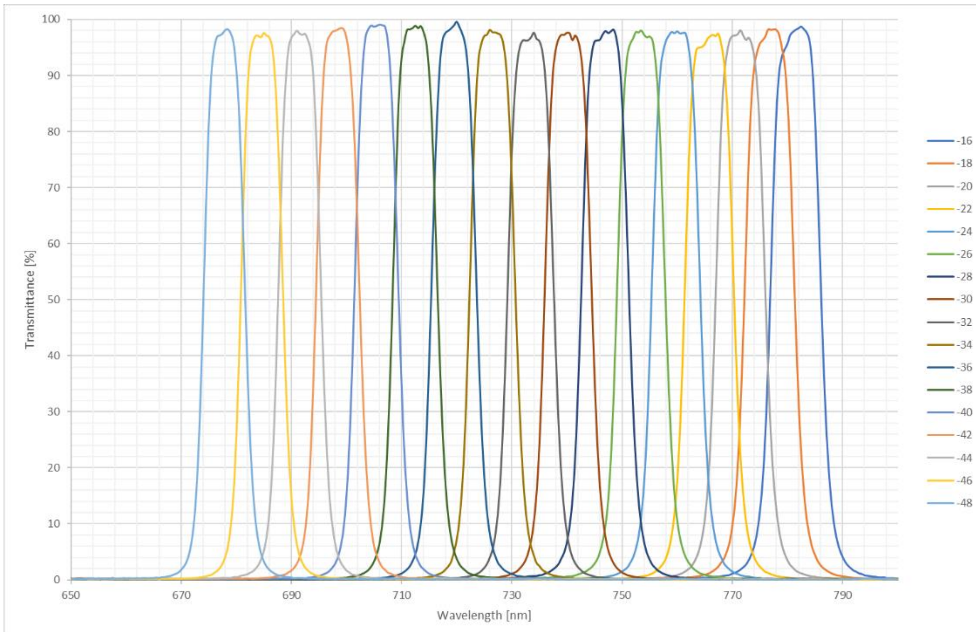

Figure 5. Measured transmittance along the spectral direction.

The measured FWHM for equally spaced spectra can be found in the figure below. The change of FWHM along the spectral gradient shows a linear behavior.

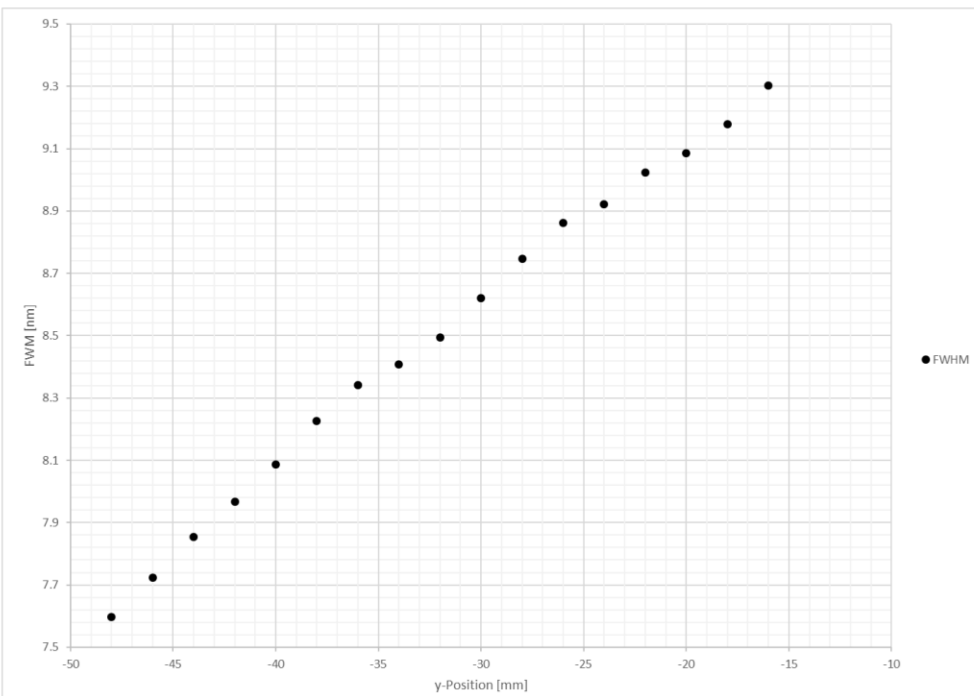

Figure 6. Measured FWHM along spectral direction.

The defined maximum and minimum wavelength for the gradient filter are 670 nm and 780 nm. Figure 7 shows measurements close to these two wavelengths versus the template.

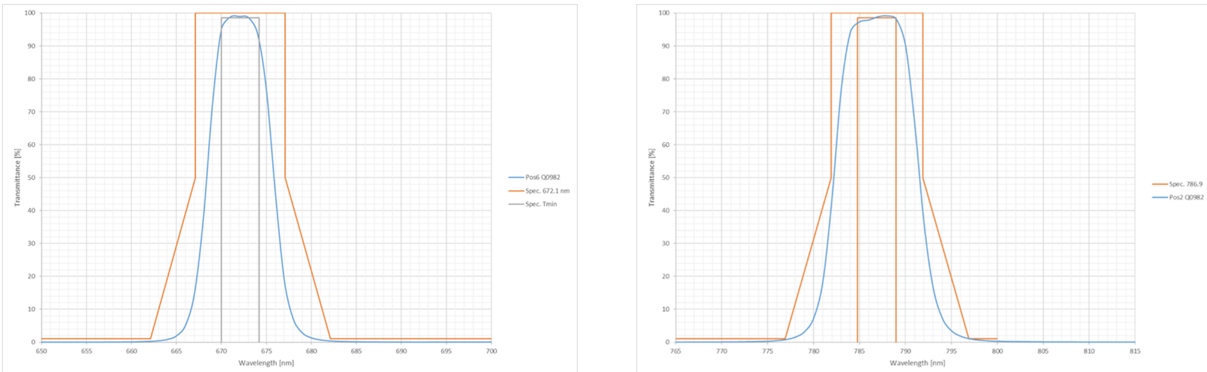

Figure 7. Measured transmittance of manufactured LVF at maximum and minimum wavelength

It can be seen that at 780 nm the FWHM ist close to the filter template while at 670 nm a slight margin can be found. For both curves a maximum transmittance of more than 98% is shown but in both cases no transmission > 98% over 4.2 nm width is achieved. To achieve this, an almost rectangular filter would be necessary which a much more complicated coating design resulting also in steeper band edges.

To demonstrate the approach to realize a blocking from 650 nm to 800 nm again two spectra at maximum and minimum wavelength are shown. The blocking width of 150 nm is achieved by design on both sides of the band pass.

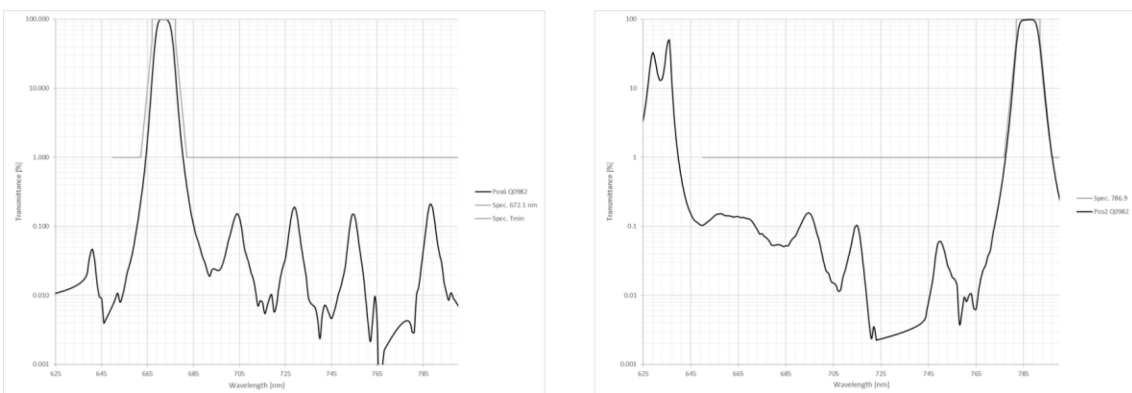

Figure 8. Measured blocking performance for LVF at minimum and maximum position.

The following two pictures show the LVF during manufacturing at wafer level (left hand side) and after application of the black mask (right hand side). The black mask will be discussed in detail in the next section. On both pictures also a distribution in spatial direction can be found. This is caused by the radius of the coating chamber and cannot be influenced beside increasing the coating chamber. This is not part of the discussion in this paper.

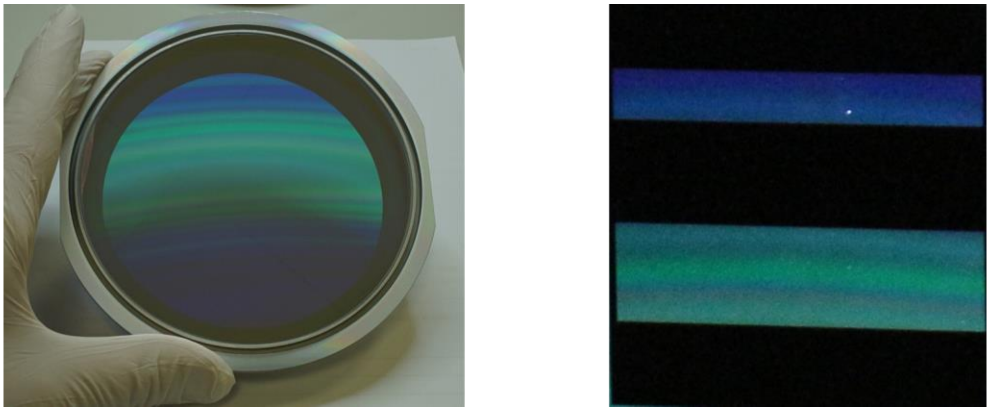

Figure 9. Pictures of manufactured LVF at wafer level (left) and with applied black mask (right).

4. BLACK COATING BY PARMS

The black coating seen on the picture above was also applied by PARMS technology. The layer stack based on metallic Ti was designed to reduce reflectance in the 400 nm to 800 nm band. The black coating can be applied black in both directions (substrate and air) or with metallic behavior in substrate direction. Figure 10 shows spectral measurement of black coating at an AOI of 8°. The measured reflectance is below 1.5% in the wavelength range 400 nm to 785 nm.

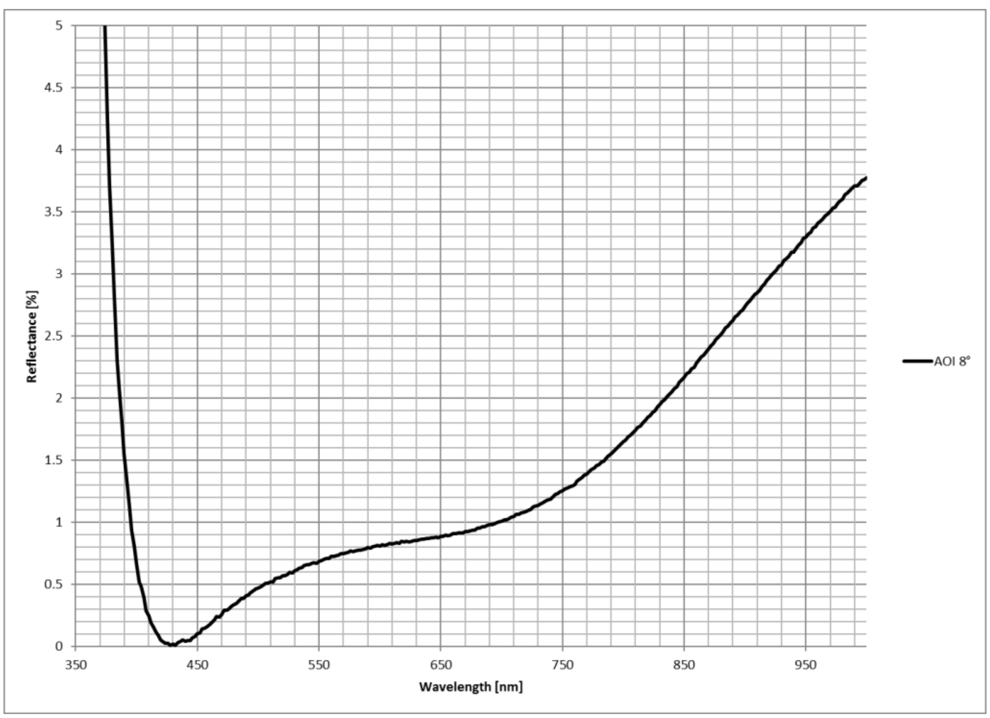

Figure 10. Measured reflectance of black coating at AOI 8°.

5. CONCLUSION

In this paper, we have demonstrated on the example of a narrow band pass filter with a FWHM < 10 nm that the PARMS process can be used for manufacturing of linear variable filters. In this case a narrow band pass filter with a FWHM < 10 nm. The presented filter performance showed a transmittance above 98% even when scaling the layer stack. Part of discussion was the impact of scaling on the filter FWHM.
Additionally, a black mask was placed on top of the LVF by means of photolithography. The black coating based on Ti showed a reflectance of < 1.5% in the 400 nm to 785 nm wavelength range.

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