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## *Design, realization and characterization of the dichroic for Euclid*

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## DESIGN, REALIZATION AND CHARACTERIZATION OF THE DICHROIC FOR EUCLID

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### INTRODUCTION

The objective of the activities comprehends the design and realization of the Dichroic filter for the Euclid Telescope.

The optical filter has the scope to split spectrally the incoming radiation in its Visible (VIS) and Near Infrared (NIR) components.

The separation between VIS and NIR will occur around 930nm, a minimum of 97% of the VIS component will be reflected on the space side surface of the window while a minimum of 95% of the NIR component will travel along the window and will find an Anti-Reflective coating on the instrument side surface. The operative angle of incidence is limited to the range 0°-18°.

The WFE (Wave Front Error) requirements (Tilt excluded – Focus included) are of 20nm rms in transmission and 15nm rms in reflection at the operative temperature range of 160÷130K. It is considered very important to guarantee the same performances also at ambient temperature where the filter is mounted and aligned in the telescope.

The challenge to satisfy the requirements was in the combination of obtaining on the same object high spectral performances and absolute flatness of the first reflecting surface and very low wave front error in transmission of the whole optic.

### DICHROIC COATING DESIGN

The spectral performances that SES (Selex ES) manufactured for the BS-FD (Beam Splitter-Full Dielectric) coating have been designed also to flatten to a very low level the reflection in the wavelength range from 400nm to 550nm.

Fig. 1 and Fig. 2 show R % and T % performances of the self-standing BS-FD coating (Design = Red Line / Measured = Blue Line).

By design the spectral performances of the BS-FD coating have been optimized at AOI = 9°.

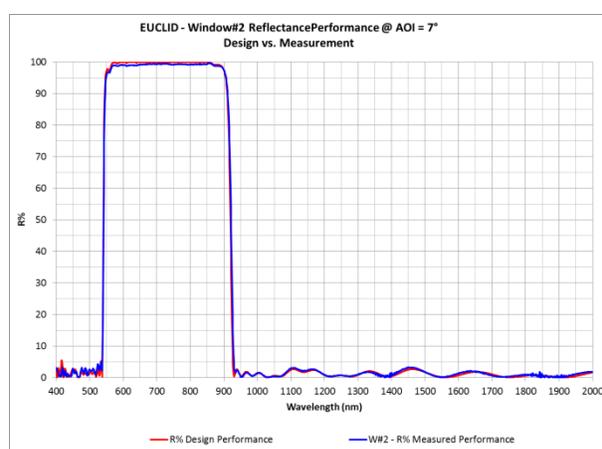


Fig. 1 Measured Spectral reflection in air @293K of the BS FD coating + window vs. design

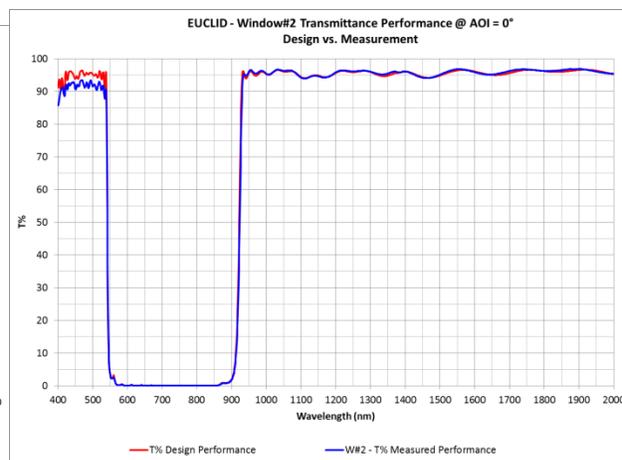


Fig. 2: Measured Spectral transmission in air @293K of the BS FD coating + window vs. design

### DICHROIC FILTER SPECTRUM

To complete the optic we have applied an Anti-Reflective coating on the second surface of the window. In this case the AR coating has not been optimized to eliminate the reflection also in the range 400nm to 550nm as it was outside the requirements but if desired this can be obtained developing an A/R coating with a proper design. The complete spectral performance of the dichroic filter measured in T% (Transmission and R% (Reflection) is then showed in Fig. 3, Fig. 4, Fig. 5

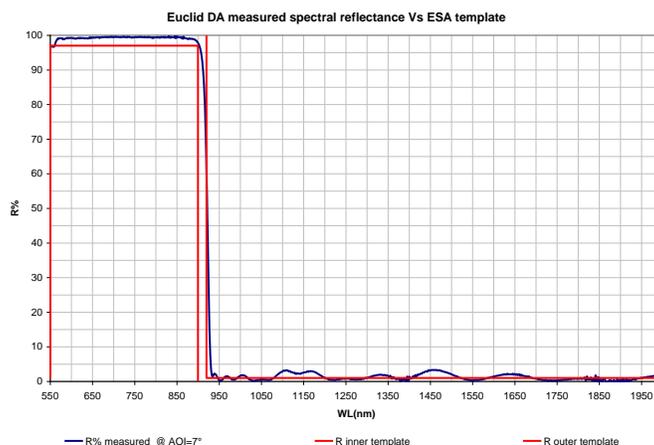


Fig. 3: Measured R% @ AOI=7° in air @ 293K Vs required performances (red template)

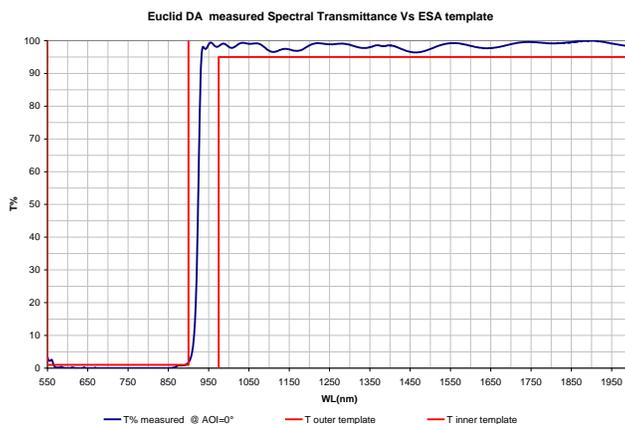


Fig. 4: Measured T% @ AOI=0° in air @ 293K Vs required performances (red template)

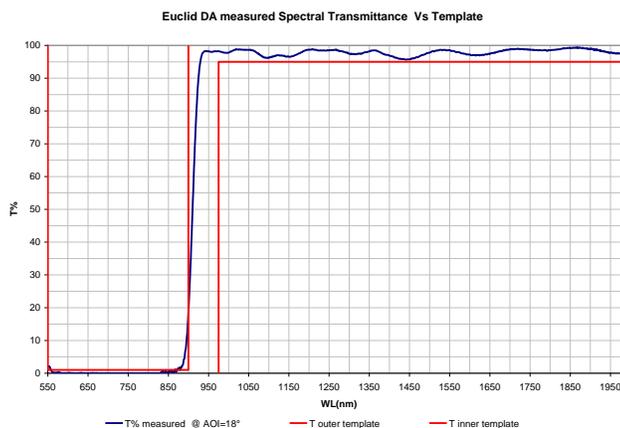


Fig. 5: Measured T% @ AOI=18° in air @ 293K vs. required performances (red template)

**WFE CONTROL**

In order to compensate the mechanical stress induced by the BS FD coating on the substrate we have used two different approaches:

1. SiO<sub>2</sub> compensation after BS coating
2. Pre-deformation before BS coating

For each compensation technique the dichroic plate's optical performances have been measured at ambient temperature while for the first of the two solutions the measure has been confirmed also at cryogenic temperature. All the measurements have been accomplished over a Clear Aperture of Ø100mm.

**CASE 1: SiO<sub>2</sub> COMPENSATION**

In this case it has been feasible to consider depositing a quartz layer on the opposite surface of the BS up to compensate its deforming stress. The necessary SiO<sub>2</sub> thickness has been predicted by studying the SiO<sub>2</sub> deformation of a blank window, this has enabled to compensate the BS coating deformation only through n.2 iterations. The realization workflow of the Dichroic Filter according to this approach is indicated in Fig. 6.

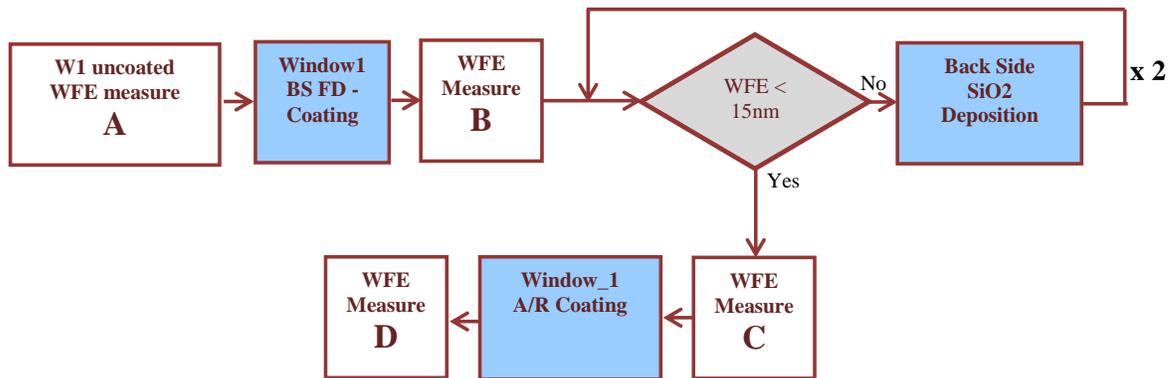


Fig. 6: Dichroic Manufacturing steps and WFE control (SiO<sub>2</sub> compensation approach).

In Tab. 1 the WFE results in Reflection at ambient temperature clearly indicate the positive achievements obtained with this approach (for cases refer to the workflow steps of Fig. 6). It can be noticed, comparing case\_C and case\_D in Tab. 1, that the contribution of the Anti-reflecting coating to the overall WFE of the Dichroic Filter is negligible.

CASE	Measured quantity	WFE Tilt & Piston removed Rms (nm)
A	Uncoated Side B Reflection	14
B	BS FD coating Side B Reflection	107
C	BS FD coating Side B (Quartz layer on side A) Reflection	16
D	BS FD coating Side B (Quartz layer + AR on side A) Reflection	16

**Tab. 1** WFE performances in reflection for the case SiO<sub>2</sub> compensation

CASE	Measured quantity	WFE Tilt & Piston removed Rms (nm)
A	Uncoated transmission	9
D	BS FD coating Side B (Quartz layer + AR on side A) Transmission	14

**Tab. 2** WFE performances in transmission for the case SiO<sub>2</sub> compensation.

In Tab. 2 the results from the WFE measurements in Transmission were also providing values well within the requirements.

**CASE 2: PRE-DEFORMATION CASE**

In this case the optic has been properly polished in order to have a profile that could be directly compensated by the BS coating itself.

In order to define how to pre-deform the optic, a window having the same dimensions of the Dichroic Filter has been used to investigate:

- The deformation in terms of WFE due to the BS-FD coating,
- The shape to apply to a blank optic to obtain the necessary pre-deformation,
- The fine adjusting of the reflected WFE value by applying a thin layer of SiO<sub>2</sub> on the backside of the window.

Once obtained this information the workflow in has been defined for the realization of the Dichroic Filter following this approach.

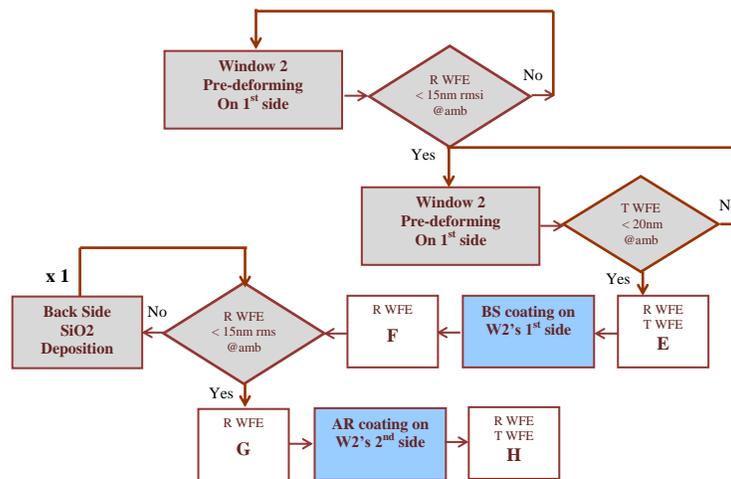


Fig. 7 Dichroic Manufacturing steps and WFE control (Pre-deformation approach).

The use of a thin layer of SiO<sub>2</sub> to complete the compensation was a deliberate choice to maintain a safety margin on the preparation of the optic but it was not necessary after all.

In the table of Tab. 3 the WFE results in Reflection at ambient temperature clearly indicate that also this approach has been successful and also in this case the contribution of the Anti-reflecting coating to the overall WFE of the Dichroic Filter is negligible.

CASE	Measured quantity	WFE Tilt & Piston removed Rms (nm)
E	Uncoated Side B Reflection	94
F	BS FD coating Side B Reflection	20
G	BS FD coating Side B (+ SiO <sub>2</sub> on side A) Reflection	15
H	BS FD coating Side B (+ SiO <sub>2</sub> & AR on side A) Reflection	15

Tab. 3 WFE performances in reflection for the case Pre-deformation.

CASE	Measured quantity	WFE Tilt & Piston removed Rms (nm)
E	Uncoated transmission	19
H	BS FD coating Side B (+ SiO <sub>2</sub> & AR on side A) Transmission	19

Tab. 4 WFE performances in transmission for the case Pre-deformation.

Even the results of WFE measurements in Transmission are within the requirements (see Tab. 4).

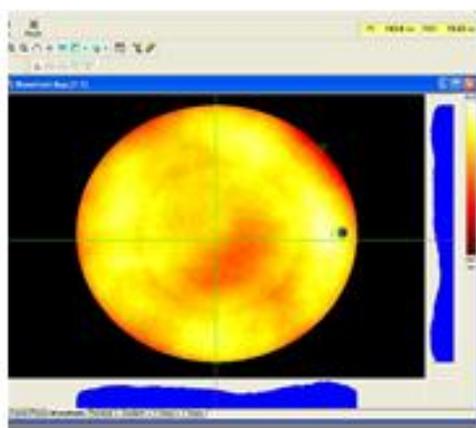
### WFE MEASURE AT CRYOGENIC TEMPERATURE

In both the approaches excellent results have been obtained in terms of WFE in reflection (BS surface) and Transmission, anyway only the Dichroic Filter realized with the SiO<sub>2</sub> compensation has been selected to be measured also at cryogenic temperature (160K) and very close to operative conditions (130÷160K).

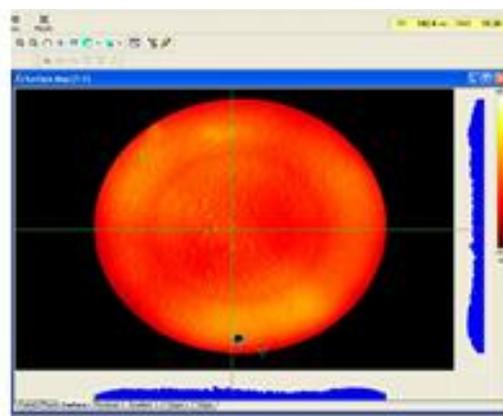
The dichroic filter has been fixed in a dedicated invar support flange designed to not interfere in the measure at such a low temperature and then inserted in the Thermal Vacuum Chamber where it has been cooled down in vacuum conditions. In Fig. 8, 9 and 10 the WFE rms values and maps (Focus Included) of the compensated Dichroic Filter are resumed.

	Temperature (K)	Air	Vac	WFE Tilt & Piston removed Rms (nm)	Requirement Tilt & Piston removed Rms (nm)
BS coating Reflection	293	x	-	16	
	293	-	x	15	
	160	-	x	15	< 15
	293	-	x	15	
	293	x	-	16	
Transmission	ambient	x		14	
	160		x	15	< 20
	ambient	x		15	

Fig. 8: WFE performances @ different temperatures (case SiO<sub>2</sub> compensation).

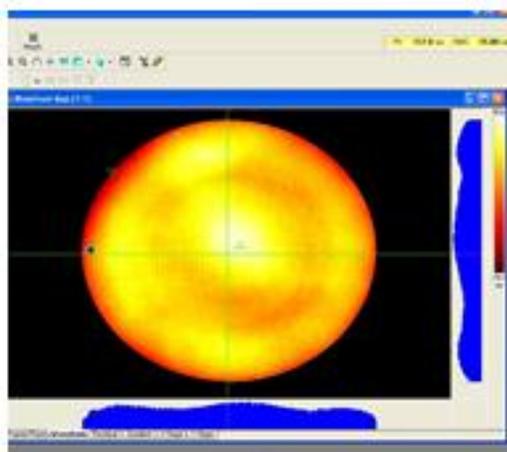


Reflected WFE @ 293K

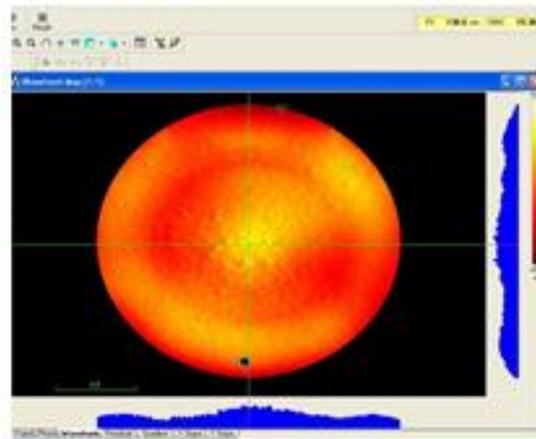


Reflected WFE @ 160K

Fig. 9: WFE maps in reflection ambient vs. cryo temperature.



Transmitted WFE @ 293K



Transmitted WFE @ 160K

Fig. 10: WFE maps in transmission ambient vs. cryo temperature.

## CONCLUSIONS

The results from the tests accomplished on the two Dichroic Filters show performances that are very well aligned with the requirements.

Besides, the WFE variation between ambient and operational environment has been limited and, as a goal, the WFE performances have been met both at ambient and operational environmental conditions.



Finally comparing the two different approaches to obtain the desired flatness of the optic we can consider that while Case\_1 (SiO<sub>2</sub> Compensantion) is definitely easier to control and apply for quartz substrates, Case\_2 can be applied to any substrate material.

Fig. 11: Dichroic Filter in its mounting frame

## ACKNOWLEDGEMENTS

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## REFERENCES

- [1] V.S. Doladugina, "Technique for estimating wavefront deformation when monitoring the homogeneity of large blanks of optical glasses" *J. Opt. Technol.* 70, pp. 120-124, February 2003.