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High performances optical coatings for Earth observation and Climate monitoring

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ABSTRACT

For several years, CILAS has developed an expertise in the field of optical thin films deposition and in-situ visible and infrared optical monitoring techniques that enables us today to successfully answer such increasingly request of space systems for Earth observation and Climate monitoring. In particular, Dual Ion Beam Sputtering technology (DIBS) and Plasma Ion Assisted Deposition (PIAD) allow us to guarantee the production of coatings that are nearly insensitive to temperature and atmospheric conditions.

We first present the results of the manufacturing of the high performances optical coatings for Microcarb Instrument. MicroCarb is designed to map sources and sinks of carbon dioxide (CO2), the most important greenhouse gas, on a global scale. The instrument on board MicroCarb is an infrared passive spectrometer operating in four wavelengths using an echelle grating to achieve spectral dispersion.

In this paper, we present also the manufacturing results of a dichroic beamsplitter dedicated to Earth observation, which has been designed to transmit light in the [800-900nm] spectral range, whereas reflecting the [450-700nm] spectral range for 45° angle of incidence. The front face involves multidielectric coating structures based on high-pass functions. The rear face requires an antireflection coating in the [800-900nm] spectral range, designed to compensate the bending induced by the front face coating in order to reach the flatness requirements of 10 nm rms.

Keywords: Plasma ion assisted deposition, PIAD, Dual ion beam sputtering technique, DIBS, dense coatings, interference filters, dichroic, climate monitoring, earth observation.

1. INTRODUCTION

Based on an innovative concept permitting the acquisition of 4 spectral bands using a single split-pupil telescope, spectrometer and detector, MicroCarb will be able to monitor very precisely CO2 gases concentration in the atmosphere. This CNES mission, which instrument is a passive Short Wave InfraRed (SWIR) spectrometer (Figure 1) manufactured by Airbus Defense and Space [1], will help scientists to better understand the planet's major ecosystems and gain a clearer picture of its carbon budget at regional scales. After integration at Airbus facilities in Toulouse, MicroCarb is currently in qualification at CNES facilities in Toulouse and its launch is scheduled in 2023.

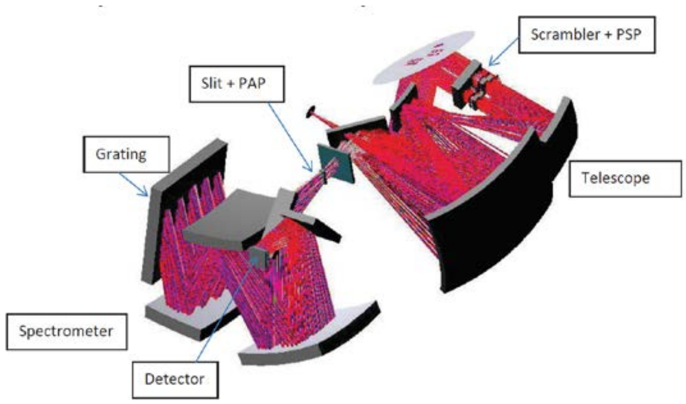

Figure 1. Optical design of MicroCarb instrument

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In this paper, we present also the manufacturing results of a dichroic beamsplitter dedicated to Earth observation, which has been designed to transmit light in the [800-900nm] spectral range, whereas reflecting the [450-700nm] spectral range for 45° angle of incidence. The front face involves multidielectric coating structures based on high-pass functions. The rear face requires an antireflection coating in the [800-900nm] spectral range, designed to compensate the bending induced by the front face coating in order to reach the flatness requirements of 10 nm rms.

Manufacturing of such multilayers coatings has required a good knowledge and master of all the parameters involved in the production process, in particular an accurate optical monitoring system during deposition is necessary to ensure the demanding spectral performances. Dense technologies (DIBS and PIAD) have been used, dedicated samples and prototype models have been developed to guarantee the spectral response of the coatings deposited on the flight models.

Experimental results of qualification tests are presented and show reliability and compliance of overall components with space environment and instruments life-time.

2. OPTICAL COATINGS FOR CLIMATE MONITORING: MICROCARB MISSION

MicroCarb mission will allow the acquisition of 4 spectral bands in the near infrared region. As a single detector is used, it is mandatory to separate the 4 spectral channels in the spatial direction. This is obtained with 4 slits in the focal plane and 2 sets of prisms to split the field and manage the global alignment [2].

The sketch of the optical path is given in Figure 2. First the optical beam meets the PSP assembly constituted of 4 “Pupil separation prisms” (one for each spectral band), then the beams enter the cryostat through a window (common for the 4 spectral bands). Once into the cryostat, the beams meet the PAP assembly constituted of 4 “Pupil Alignment Prisms” (one for each spectral band), and then the Detection Filters assembly, constituted of 4 Filters (one for each spectral band), located just before the detector.

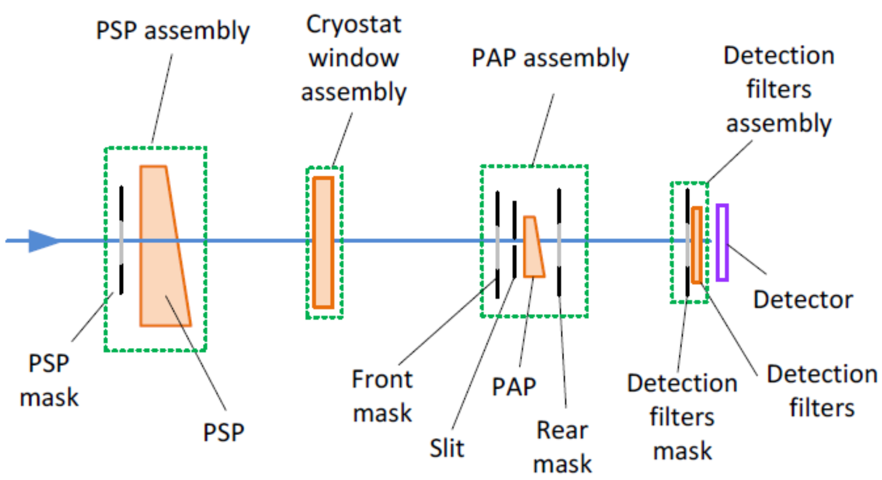

Figure 2. Sketch of the Microcarb optical path

For this project, CILAS has designed, developed, manufactured and qualified all the coatings for the PSP and PAP prisms, the cryostat Window and the Detector Filters.

2.1 MicroCarb filters design

In order to achieve the requirements in each of the four spectral channels, the design of each filter takes into account the broad out-of band rejection range (300-2700nm), the bandwidth and steepness of in-band transmission range, and the lightning conditions and polarization effects, leading to a high number of layers of different materials. For each channel, several coatings (filter, blocking and antireflection functions) are used on several faces in order to reach the global transmission and rejection requirements. Furthermore, these coatings are deposited on small dimensions substrates of few millimeters size and coating induced-stress compensation is particularly studied.

The transmission of each spectral channel is specified for the overall channel, therefore called "global transmission". It includes all optical components of the spectral channel addressed in this specification: PSP, PAP, Detection filters, and Cryostat window, plus the absorption of materials (substrates and coatings) of each component of the channel and takes into account the incident angles.

Each spectral channel has thus a “global requirement” in terms of central wavelength (λ0), full-width half medium (FHWM), in-band transmission (Tmin and Tave), as indicated in Table 1 and all elements located on the optical path contribute to the overall performance.

Table 1. “Global Requirements” of the 4 spectral channels

	B1	**B2**	**B3**	**B4**
λ0	763,5 nm	1607,8 nm	1273,4 nm	2037 nm
FWHM	10.5 nm	22.1 nm	28 nm	17.5 nm
Tmin	85%	90%	90%	90%
Tave	90%	95%	95%	95%

Moreover, the broad out-of band rejection range (300-2700nm) is too severe to be achieved by a single optical element. The rejection function is therefore distributed on the PSP Prism and the Detector Filter (FD) elements.

Anti-reflection functions are used for the Cryostat Window and PAP prism elements. However, if the global level of rejection is not reached thanks to PSP and FD, an additional blocking can be added on the PAP Prism instead of the antireflection functions (this is the case for B4 band).

The required optical functions need thus to use complex multidielectric coating structures, combinations of Fabry-Perot type filter structures and high and low pass structures:

- In order to guarantee the centering of the band, a multiple half wave Fabry-Perot filter is used, for which the spectral response is mastered with the help of a direct real-time optical monitoring system.
- In order to guarantee the bandwidth of the filter, dense coating technology that leads to dense microstructure of layers is used in order to obtain a high reproducibility of refractive indices.
- In order to reach the performances of out-of band rejection, it is necessary to eliminate the harmonics of the band pass filter with the help of blocking filters.

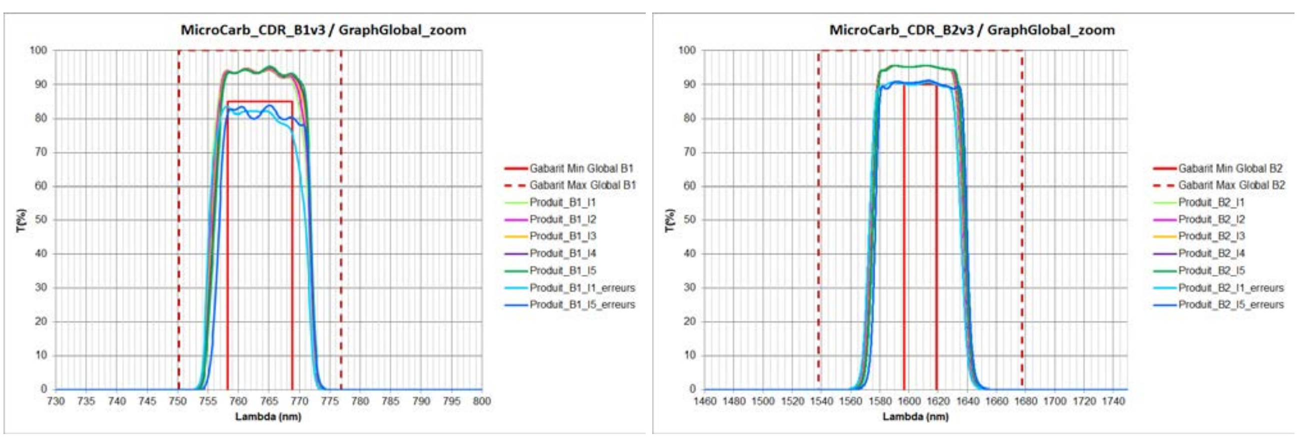

Figure 3. Global performance in transmission of B1 (left) and B2 (right) channels

In Figures 3 and 4, are presented the global performances in transmission for each channel. Curves « Produit_Bi_l1 to l5 » represent the global transmission along 5 points of each channel area on the detector. Curves « _erreurs » show a simulation of the cumulative effect of manufacturing errors of each coating encountered in the optical path.

The performances are in accordance with the specifications. However, the simulation of the manufacturing errors leads to a significant decrease of the transmission (in particular for B1 channel). This is therefore an important risk for the performance of the MicroCarb instrument.

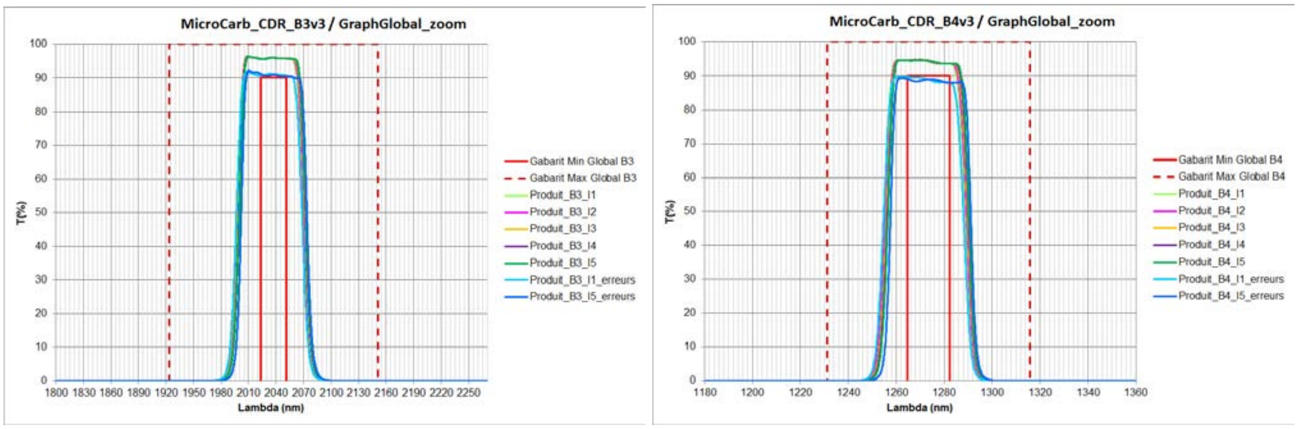

Figure 4. Global performance in transmission of B3 (left) and B4 (right) channels

In Figures 5 and 6, are presented the global performances in rejection over [300-2700] nm for each channel, which are compliant with the specifications.

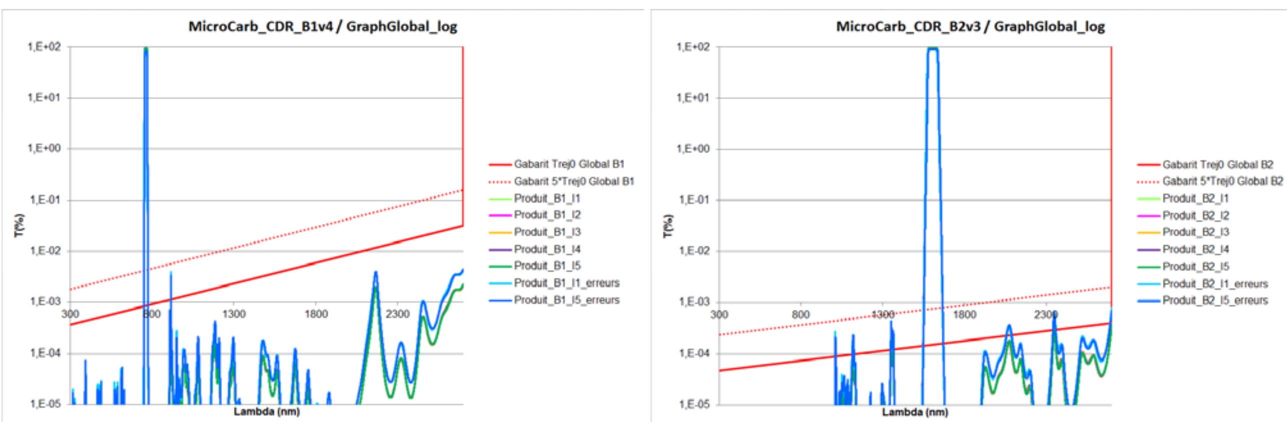

Figure 5. Global performance in rejection of B1 (left) and B2 (right) channels

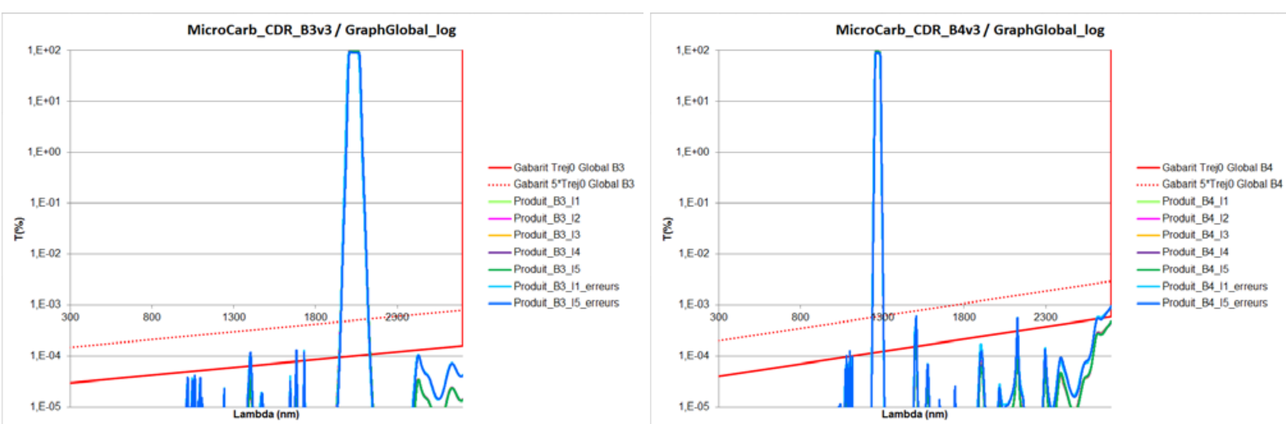

Figure 6. Global performance in rejection of B3 (left) and B4 (right) channels

2.2 Manufacturing and qualification

All the coatings have been done with Dual Ion Beam Sputtering technique (DIBS) and in-situ optical monitoring [3]. This technology uses a first ion beam gun for sputtering a target and a second one for compacting the sputtered material (Figure 7). The use of a neutral ion beam allows sputtering purely dielectric material or metallic material targets. Moreover, as the travel of the sputtered material from target to substrate is completely unimpeded, this is the best technology for producing very high quality coatings and very dense layers. This technology is intensively used for manufacturing very narrow filters for the optical telecommunication market. This is also an ideal technology for space applications as there is no measurable spectral shift between air and vacuum [4] [5] [6]. Moreover, the IBS technique (Ion Beam Sputtering which uses only one ion beam gun for sputtering a target) has been widely studied for the production of low loss and low scattering mirror involved in the VIRGO project [7].

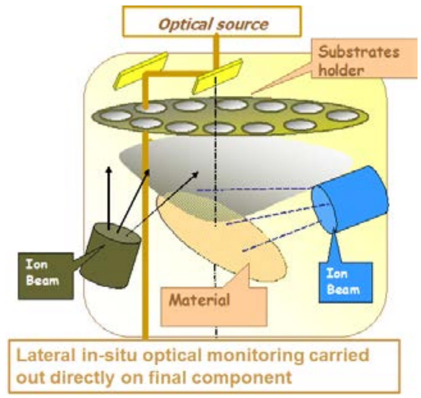

Figure 7. Dual Ion beam sputtering principle

We present in Figures 8 and 9 the results of the manufacturing of the four Detector Filters (FD). Green curves represent the theoretical transmission (for specified incident angles and for normal incidence). Yellow and orange curves show the spectral measurements realized directly on the 3 flight components manufactured for each channel and the transmisssion obtained is very close to the expected.

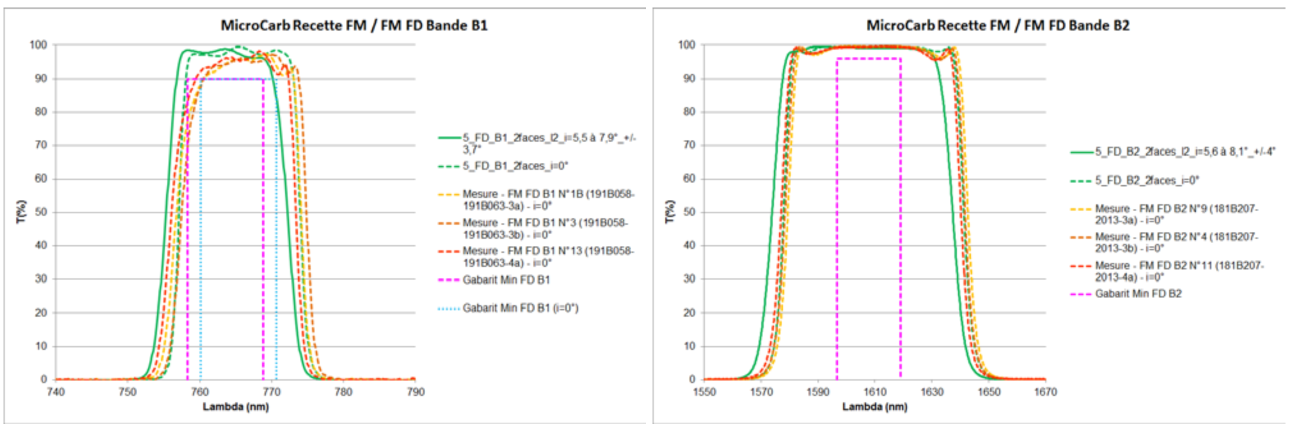

Figure 8. Performance in transmission of B1 (left) and B2 (right) Detector Filters flight models.

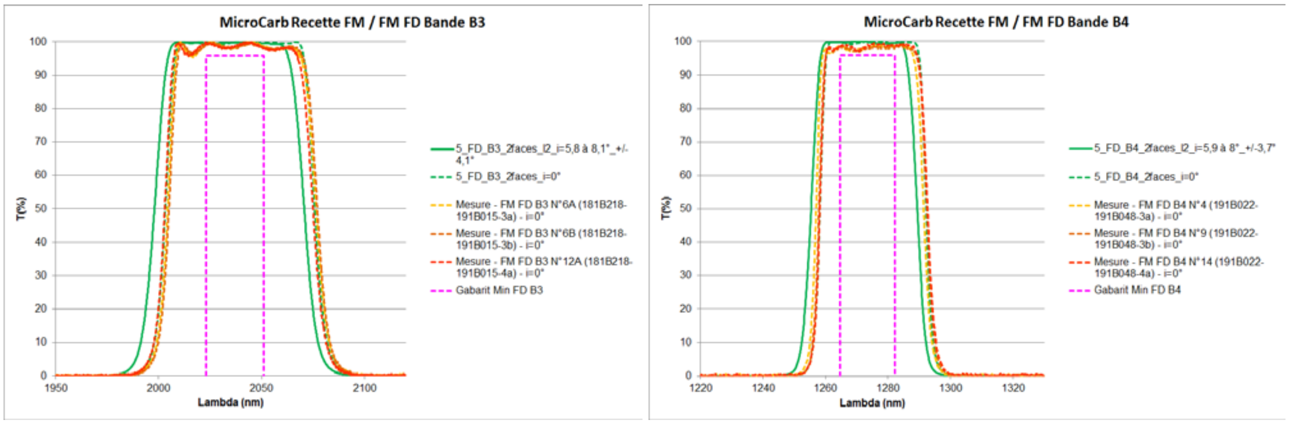

Figure 9. Performance in transmission of B3 (left) and B4 (right) Detector Filters flight models.

On Figure 10, an example of the spectral measurement in rejection is given for the B2 channel in log scale. Green curves represent the theoretical transmission. The spectral measurement (blue curve) realized directly on one sample coated with the flight components is very close to the expected.

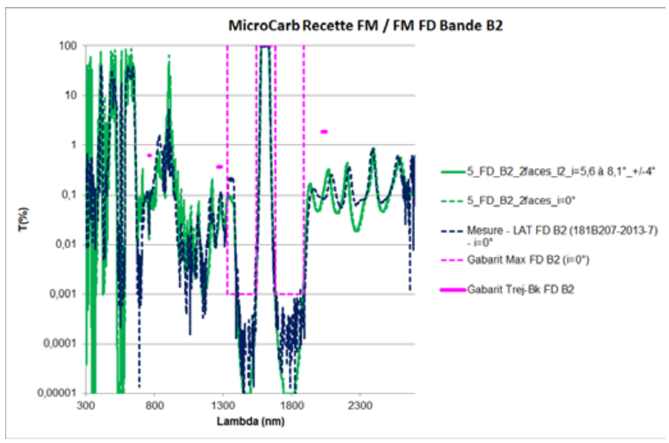

Figure 10. Performance in transmission (log scale) of B2 Detector Filter.

Polarisation sensitivity is also an important requirement for the mission. On Figure 11 we have plotted the polarisation sensitivity (red curve) calculated from transmission measurements in S and P polarisation for B2 channel, compared the the theoretcial curve (blue curve), showing also here a very good agreement.

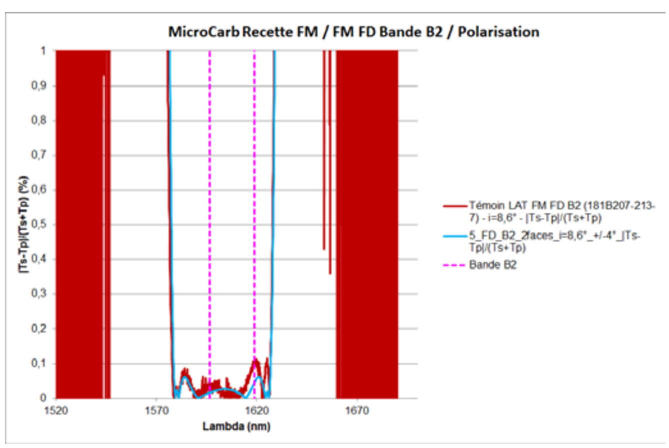

Figure 11. Polarization sensitivity of B2 Detector Filter.

All the susbtrates dedicated to realization of the MicroCarb coatings have been polished by Winlight company (Pertuis, France), whith dedicated shapes (wedges, windows, prisms, stripes), materials (Fused silica, Silicon, colored glass) and dimensions (4x4mm² to 40mm diameter). Some pictures of coated components are presented on Figure 12.

Figure 12. Pictures of optical components for MicroCarb: PSP, Cryostat Window, PAP, Detector filter (from left to right)

As for each space project, several qualification tests in temperature, humidity, thermal vacuum, radiations,… have been successfully led on qualification models and Lot Acceptance Tests (LAT) samples, which show the reliability of these coatings in space environment, showing no degradation as well for spectral measurements as for cosmetic performances.

CILAS thanks Airbus Defense and Space and the CNES for entrusting it with this great project, and all the people involved for the fruitful collaborative work throughout the project.

3. DICHROIC COATING FOR EARTH OBSERVATION: THE CHALLENGE OF WFE

In this paper, we present also the manufacturing results of a dichroic beamsplitter dedicated to Earth observation, done with PIAD (Plasma-Ion Assisted Deposition) model SYRUSpro 1350 (Bühler). Such technology is based on evaporation with electron gun and uses a RF plasma source for compacting the evaporated material [8]. The density of the deposited layer is very close to the bulk material and enables the coatings to be nearly insensitive to environmental parameters. This technology is well adapted to severe environments as it allows the production of very dense layers and high quality coatings [9].

The use of an in-situ optical monitoring system in visible and near infrared range (300-2500nm) permits to reach severe spectral specifications and to have a very good agreement with the theoretical designs [10].

The dichroic beamsplitter has been designed, to transmit light in the [800-900nm] spectral range, whereas reflecting the [450-700nm] spectral range for 45° angle of incidence. The front face involves multidielectric coating structures based on high-pass functions. The rear face requires an antireflection coating in the [800-900nm] spectral range.

Manufacturing of both functions involved the definition of a monitoring strategy and most of the layers have been optically monitored.

On Figure 13 are presented spectral measurements, at 45° angle of incidence, in P and S polarization, done on two dichroic beamsplitters manufactured in different coating batches.

Compared with the theoretical design, the measurements are in very good accordance, both in terms of transmission and spectral centering. Moreover, the performances of the two coating batches show a very good reproducibility.

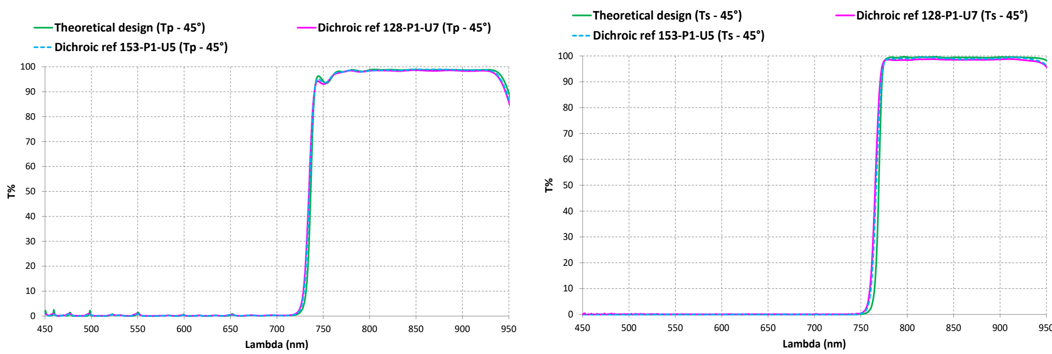

Figure 13. Spectral response measurements at 45° angle of incidence, in P (left) and S (right) polarization in [450-950nm] spectral range of two dichroic beamsplitters manufactured with PIAD coating technology.

With dense deposition techniques, the density of the deposited layer is very close to the bulk material and enables the coatings to be nearly insensitive to environmental parameters. A drawback of such dense techniques is that it induces some stress inside the multilayer stack that leads to wavefront error [11]. The antireflection coating has thus been designed for the rear face in order to compensate the bending induced by the front face coating, and to reach the flatness requirements of 10 nm rms.

In Table 2 and Figure 14 are presented the WFE measurements done over a 60mm diameter of one dichroic beamsplitter at different manufacturing steps. Polished substrate shows a good surface quality before coating (23.7nm P-V and 2.8nm rms). After dichroic coating on the front face, the bending highly increases as expected with dense coatings (865 nm P-V and 237nm rms). After dedicated antireflection coating on the rear face, we can observe the success of the compensation with a flatness within the 10nm rms requirements (41.3nm P-V and 6.9nm rms).

Table 2. Flatness values (Peak-to-valley and rms) after polishing, after dichroic coating on front face and after antireflection coating on rear face, over a 60mm diameter.

Flatness	After polishing	After Dichroic coating (front face)	After Antireflection coating (rear face)
PV	23.7 nm	865 nm	41.3 nm
rms	2.8 nm	237 nm	6.9 nm

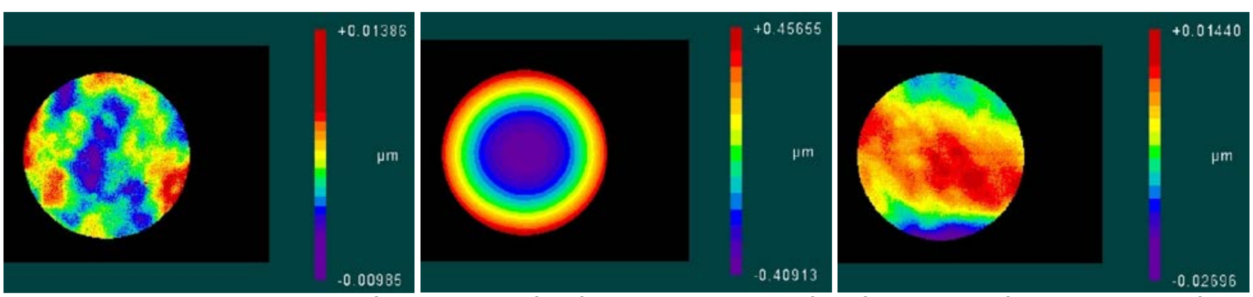

Figure 14. Flatness measurement after polishing (left), after dichroic coating on front face (center), after dedicated antireflection coating on rear face (right).

CONCLUSION

In this paper, we have presented some complex optical functions that have been manufactured with DIBS and PIAD technique with very good compliance with theoretical design.

In particular, the results of the manufacturing of the high performances optical coatings for Microcarb Instrument have been presented. For the 4 channels, 23 different coatings (filter, blocking and antireflection functions) have been designed, developed, qualified and deposited on 14 different components in order to reach the global transmission and rejection requirements.

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