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MULTISPECTRAL FILTERS ASSEMBLIES FOR EARTH REMOTE SENSING IMAGERS

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I. INTRODUCTION:

With the aim to expand its capability to offer state-of-the-art space qualified multispectral optical filters assemblies, Sodern continues its effort to evaluate and incorporate new technologies in its designs. For many years, Sodern has been developing complex optical devices incorporating spectral filters.

In this paper, we describe the development and improvement given by applying Plasma Assisted Reactive Magnetron Sputtering (PARMS) thin film coatings. These coatings are deposited on specific wafers by CILAS with the support of Institut Fresnel. Customized stripes with both optical surfaces being fully coated are obtained by wafer cutting technique. The cemented edge-to-edge assembly is made with black opaque glue to block ghosts that can propagate from one stripe to the other by reflexion inside the filter substrate.

Besides this technological development, Sodern also investigates the risk of Electro-Static-Discharge in diaphragm and filter assemblies. Indeed, optical coatings that combine metal and multi-dielectric films on glass could accumulate charges in space environment and create damages as they are mounted close to vulnerable image sensors. Electron irradiation tests will be performed on components and assemblies to evaluate the effects and give a better assessment of the risk which is presently considered low.

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II. TECHNICAL OBJECTIVES:

A. Hardware description

For Earth remote sensing imager operating in pushbroom mode, the spectral separation is obtained via multispectral filter mounted on multi-linear detector's transparent windows. Sodern manufacturing process [1] consists of assembling frames and stripe filters by the slice with a black structural glue to build the overall multispectral filter assembly as shown in Fig. 1 hereafter.

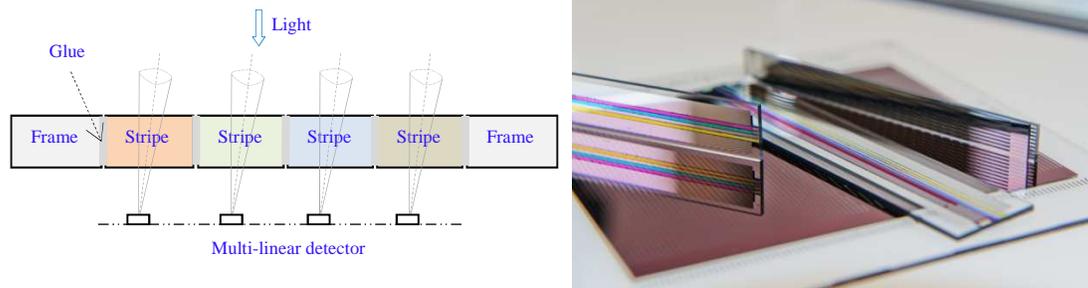


Fig. 1. Multispectral filter assembly overview

The geometry has early been designed to be compatible with commercially available detectors [2] taking into account photosensitive lines spacing separation between 720 μ m and 2 mm and glass substrate thickness around 1.5 mm. Each stripe filter is coated with various thin layers providing spectral function and includes also masking on both entrance and exit sides minimizing stray light.

B. Optical and spectral requirements

The development of a technical demonstrator named IDEFIX (Innovation and DEMonstration of Filters Xs) aims developing high-precision VNIR multispectral filters. Table 1 describes main technical specifications which apply to the realization of the narrow-band filters with FWHM (Full Width Half Maximum) band passes of about few tenths of nanometer and effective out-of-band blocking close to the band.

Table 1. Spectral requirements goal

Bi	CWL λ_c (nm)	FWHM $\Delta\lambda$ (nm)	Mean T (%)	Rejection ratio	Total integrated Scattering TIS	Slope 10% 90%
B0	415 ± 3 nm	40 ± 10%	> 80%	< 0.3%	< 0.3%	< 5 nm
B1	667 ± 2 nm	30 ± 10%	> 80%	< 0.3%	< 0.3%	< 5 nm
B2	782 ± 1 nm	16 ± 10%	> 80%	< 0.3%	< 0.3%	< 5 nm
B3	910 ± 2 nm	20 ± 10%	> 80%	< 0.3%	< 0.3%	< 5 nm

The following definitions apply for the mean value of the transmittance “(1)” over the filter bandwidth and the rejection ratio “(2)” taking into account each filter λ_i cut-on and λ_j cut-off blocking regions, the [350nm – 1100nm] limits of the CCD responsivity band and the value $R(\lambda)$ which equals the filter spectral transmittance $T(\lambda)$ times the CCD spectral responsivity.

$$Mean_T = \frac{1}{\Delta\lambda} \int_{\Delta\lambda} T(\lambda).d\lambda \tag{1}$$

$$R = 1 - \frac{\int_{\lambda_i}^{\lambda_j} R(\lambda).d\lambda}{\int_{350}^{1100} R(\lambda).d\lambda} \tag{2}$$

The total integrated scattering requirement corresponds to stray light indicating how much light is randomly deviated in space from specularly transmitted beam. A severe cosmetic requirement has been defined inside the clear apertures: no allowable pinhole and 15 microns maximum dark defects, leading to master with high quality the manufacturing steps such as photolithography process and thin film deposition.

The focal planes of Earth remote sensing imagers usually use multiple butted detectors, example Fig. 2 below Pleiades HR [3], to increase the across track field of view or swath width. The minimization of the central wavelength variation on the whole retina is a main requirement. The specification applies on the worst case corresponding to the area of covering between consecutive filters for example the right side of the first filter compared to left side of the second one. Therefore the requirement of the central wavelength (CWL) λ_c and bandshape spatial uniformity on a batch of filters is thus the critical parameter and was addressed during this study with a goal of ± 1 nm on λ_c across 80 mm and between stripes.

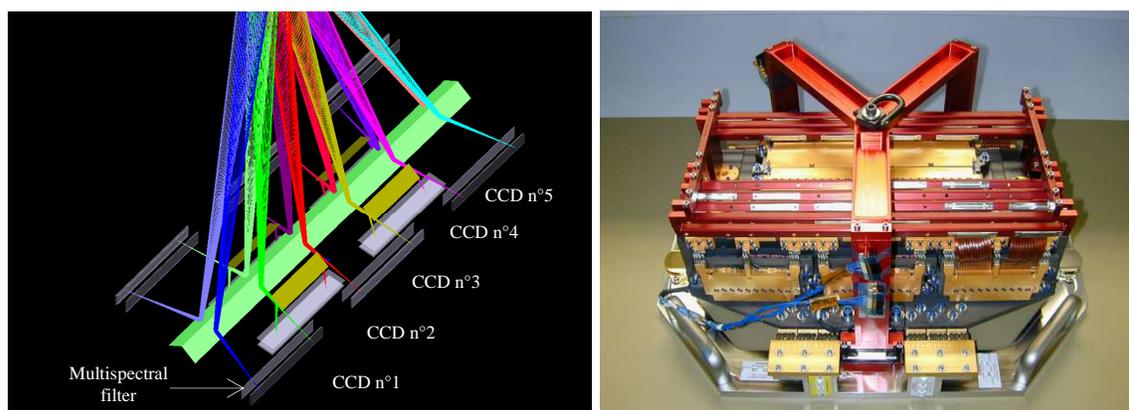


Fig. 2. Pleiades Focal Plane with 400 mm length continuous panchromatic and multispectral retinas

Plasma Assisted Reactive Magnetron Sputtering (PARMS) manufacturing deposition process has been selected at the beginning of the study, due to the following points:

- very good spatial uniformity over the entire effective area of the glass wafer and between wafers of a same batch,
- manufacturing of complex coating with very good accordance with theory.

This project has been conducted in collaboration with CILAS and Institut Fresnel. Coating designs and wafer manufacturing have been taken in charge by CILAS, with the support of Institut Fresnel for the filters coating deposition using their PARMS coating chamber (LEYBOLD Optics “HELIOS 4”).

C. Coating design description

In order to achieve demanding spectral requirements, the both faces of the wafer are used to reach the filter function: bandpass filter with a surrounding blocking zone is implemented on the front side while the remaining blocking on the rear side. Some additional design constraints have also been taken into account: blocking coating on rear side wide enough to reduce stray light reflectance on adjacent spectral bands, and a global coating stacks thickness distributed on the two sides in order to minimize substrate bending.

The resulting theoretical performances with upper and lower complete layer stacks are summarized in the graph of transmittance versus wavelength Fig 3. We expected as specified very low transmission levels in the blocking ranges.

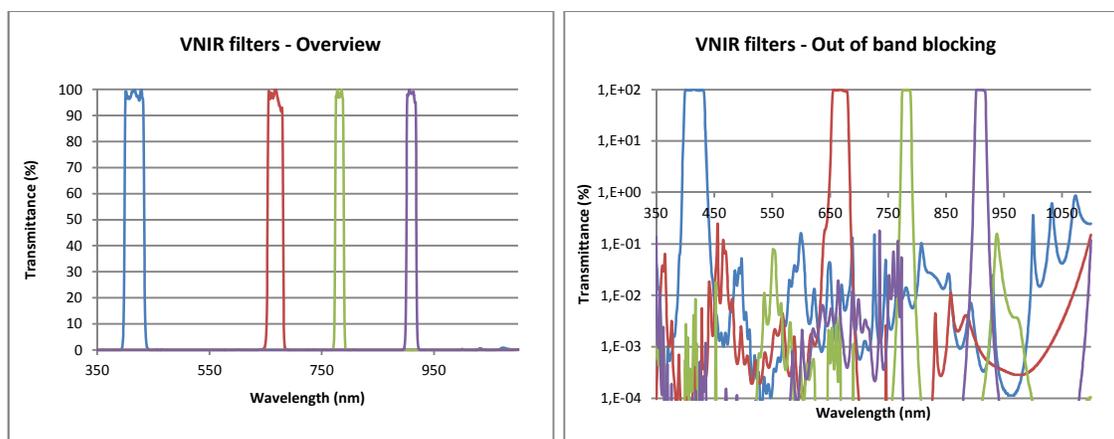


Fig. 3. Typical normalized transmission levels of all filters (the plot on the right uses a logarithmic scale)

III. MANUFACTURING:

A. Overview

Breadboard models have been manufactured in order to investigate and demonstrate feasibility and performances. Two spectral channels B0 and B2 have been manufactured (see Fig. 6) including several successive steps: implementation of black absorbing coatings on both sides of the component to constitute the diaphragms, openings of the clear apertures inside the absorbing diaphragms using lift-off technique and finally coating on both sides with bandpass filter functions. Each wafer has 24 stripes as long as 80 mm with spacing of 2 mm. The breadboarding results are depicted section B.

Further activity after wafers acceptance is focused on multispectral filter assembly and environmental qualification. Wafers are sliced within a few microns tolerance and then elementary stripes are cemented side by side. The Sodern filter assembly flowchart and the manufacturing processes are re-assessed. The cutting operations are indeed more challenging because with magnetron sputtering the deposited materials exhibits a very dense microstructure. Then at the end of this year the qualification to space environment will be demonstrated on two representative specimens of filter assemblies and coupons regions surrounding stripe filter areas on the wafers. The specific test sequence will include damp heat of 95% at +40°C for 24 hours and then thermal vacuum cycling with 10 cycles in the temperature range -15°C to 70°C and finally ageing endurance test with 50 cycles in the temperature range -15°C to 70°C.

B. Wafers experimentation

For each spectral band B0 and B2 two wafers were produced. Additional samples were coated simultaneously in the same runs; quality assurance witnesses of diameter 25 mm, 100 mm diameter witness plates for spectral uniformity expertise and other more specific samples to measure substrate surface bending due to optical coatings.

The spectral performances are very close to the theory as depicted Fig. 4 and Fig. 5. Spectral measurements have been done at Institut Fresnel with a standard Perkin-Elmer Lambda 1050 spectrophotometer and with a high detectivity fiber optic remote Optical Spectrum Analyzer (ANDO AQ 6315-A) well adapted for rejection measurement.

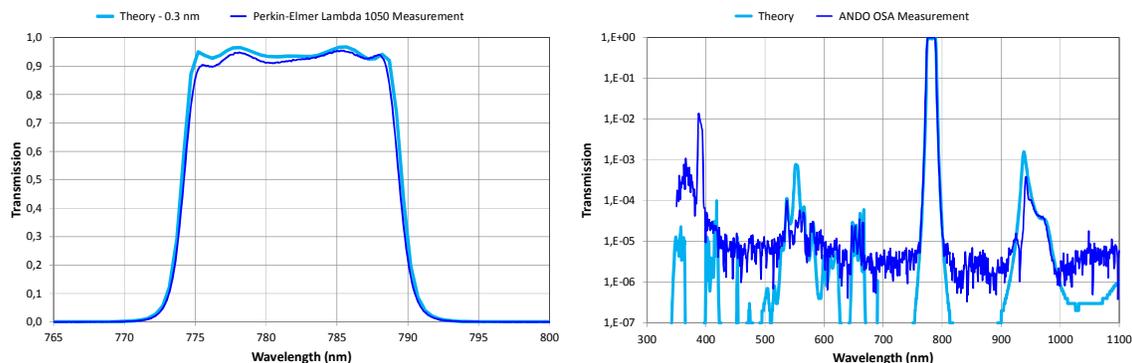


Fig. 4. Spectral performances graphs of B2 band

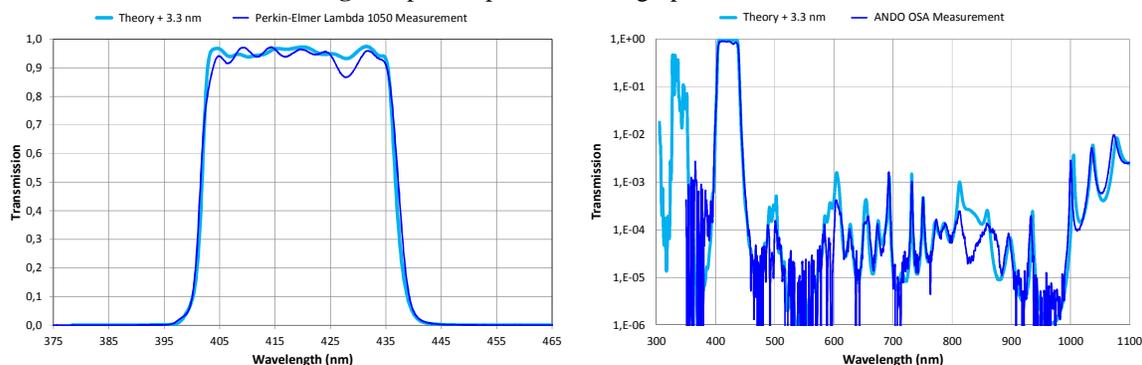


Fig. 5. Spectral performances graphs of B0 band

In addition the spatial uniformity of wafers was characterized with the help of a photometric bench previously developed at Institut Fresnel for the localized measurement of the spectral properties of coated components [4]. The following graph Fig. 7 shows the result of uniformity measurements performed on a 100 mm diameter silica substrate and on a nominal filter wafer (through the stripe absorbing slits of 700 microns in width) both coated in the same manufacturing run (B2 filter).

To determine the spatial non-uniformity of the witness substrate, high accuracy measurements of the localized spectral transmittance of the B2 bandpass filter at normal incidence are performed on a regular grid of 51 x 51 points (2 mm pitch) with the Institut Fresnel spatial uniformity bench under full automatic control. Dedicated data processing allows deriving first a false color representation of the substrate uniformity and second a prediction of the central wavelength changes along each stripes of the structured wafer. These computed results are nicely confirmed by direct spectral transmittance measurements performed with this spatial uniformity bench through the stripes of the nominal filter manufactured during the same run (Fig. 7). The uniformity performance in this case is better than $\pm 0.2\%$ for all the stripes. A little better result of about $\pm 0.1\%$ is obtained on B0 wafer. The residual shape of spatial wafer non-uniformity is similar for both filters. It is directly linked to the coating chamber properties and is quite independent of the alternated high index/low index thicknesses which obviously are different between B0 and B2.



Fig. 6. VNIR filter wafers with 110 mm diameter. The filter stripes are the long rectangular stripes on the wafer. The surrounding larger filter zones are coupon regions used for testing

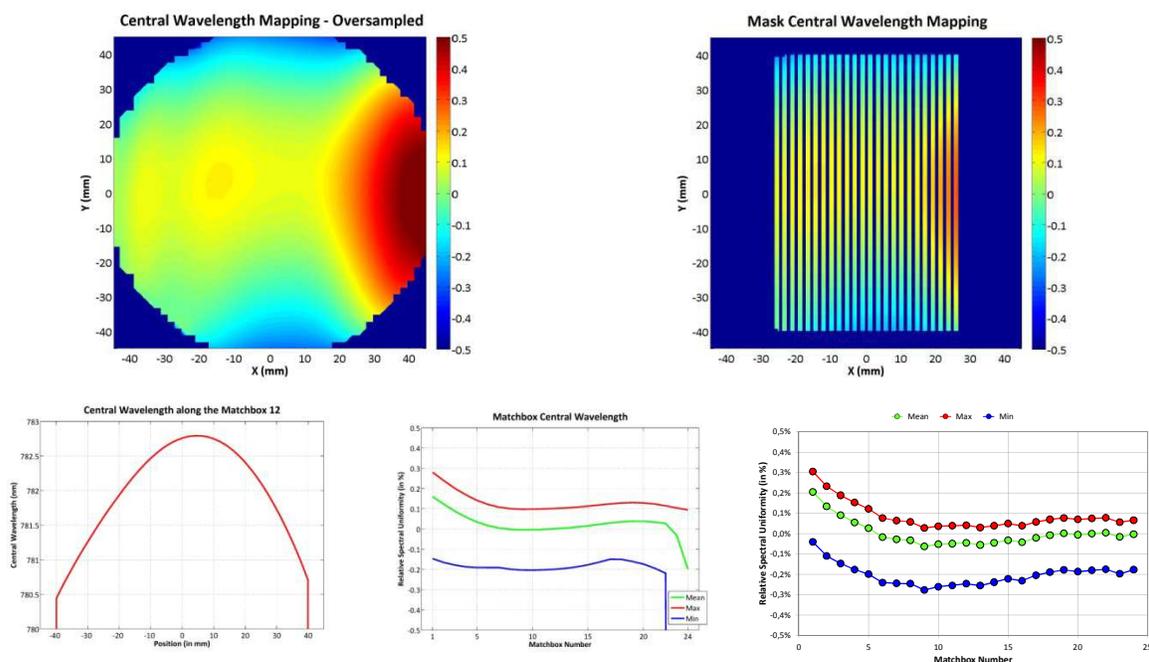


Fig. 7. Spatial uniformity graphs of B2 band

Minimizing scatter and wide angle light scattering [5] are also particularly important for multispectral filters. To face this challenge, Bidirectional Transmittance Distribution Function (BTDF) measurements of coatings and cartographies of substrate surface micro roughness were involved at Institut Fresnel. The substrate surface is a key parameter to low scatter. Indeed with PARMS process the very dense multi-layer stacks replicate the existing surface finish. Based on preliminary numerical modelling results taking into account upper and lower stacks formula, illumination conditions, micro roughness and bulk inhomogeneous, Institut Fresnel has shown a correlation between BTDF scattering behaviour at wide angle and filters design characteristics.

VI. Electro-Static-Discharge:

Besides this coating technological development, we also investigate the risk of Electro-Static-Discharge in metal-dielectric multi-layers absorbing masks and detector assembly.

Though the risk of ESD is considered low because of the moderate space particles currents on the assembly materials, the proximity of a vulnerable image sensor has prevented from putting an end to the question. The assessment of the electric potential developing during a mission lifetime is complex. If the voltage across various components increases because of charge accumulation, it could reach a critical point where the discharge is sudden and harmful. A glass substrate is rather an electrical insulator, even if not as much as pure silica. The potential depends not only on materials bulk properties but also on the assembly geometry and on the interfaces between the various pieces. Capacitive effects could take place in coating multi-layers. The filters are glued on the sensor package that is an electrical insulator.

The first part of our investigation consisted in measuring electrical bulk properties of glasses and glues by irradiating samples under a mono-energetic electron beam at SIRENE facility in ONERA. The electrons were implanted in the samples and the rising of the potential was measured by a Kelvin probe. At currents several orders of magnitude higher than the actual currents in orbit ($> \times 10000$), there is no charging of the substrate glass nor of the glues used in the filters. These materials are thus considered as conductors from an ESD point of view, i.e. they allow a continuous evacuation of charge carriers during the exposition to space radiation, which is beneficial regarding ESD risk. These results suggest that the whole filters will behave the same way.

One could fear the coatings act as barriers to charge flow, but we think they do not. Either because these metal-dielectric multi-layers are conductive, or because carriers flow via the metal layers on a small length, at most the coating thickness on the filter sides (surface conductivity, see fig. 8 below).

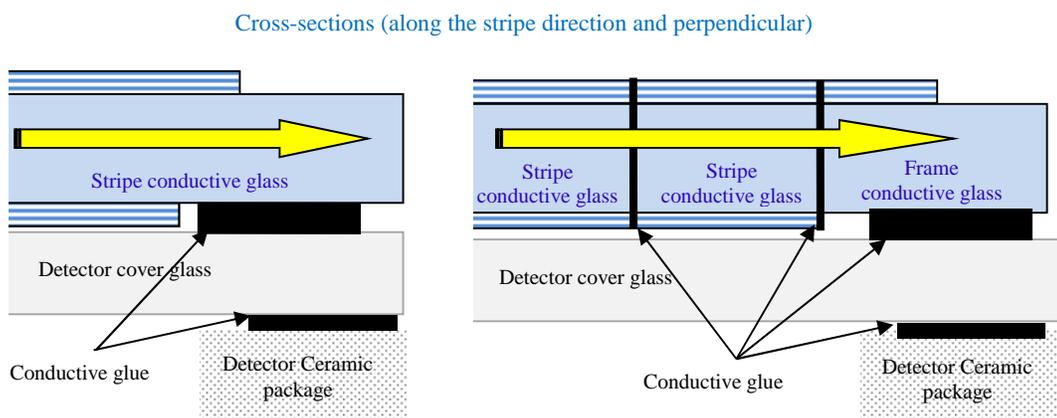


Fig. 8. Possible paths of charge evacuation: surface conductivity

The effect of the sensor package seems to be the only remaining question. We have irradiated a similar ceramic and voltage rise was observed. However this sample was a simple ceramic, fabricated with a process different from the process for a multilayer package incorporating metal tracks. Moreover data is still under analysis and the duration of the relaxation experiment following the irradiation may have been too short to assess the resistivity and to know whether charging occur under low incident current, several orders of magnitude lower. We therefore intend to irradiate filters and dummy assemblies under other conditions in the next months to confirm and prove their robustness to space charging.

VI. CONCLUSION:

The work is currently in an advanced stage of investigation and will continue until the end of this year.

Plasma Assisted Reactive Magnetron Sputtering technology enables high end functional coating with excellent uniformity. Initial results show that these hard coated optical filters offer steeper slopes compared to other traditional coated filters with deep blocking. The excellent results were also achieved partly thanks to a suitable monitoring during deposition process.

Magnetron sputtering thin film stress was evaluated from measured surface curvatures before and after coating deposition. The final flatness of wafers was appropriate, less than 10 microns for the two B2 wafers and about 20 microns for the two wafers B0 indicating a good control of this parameter during development.

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