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FOCAL PLANE FOR THE NEXT GENERATION OF EARTH OBSERVATION INSTRUMENTS

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I. INTRODUCTION

Sodern is the French focal plane provider for Earth Observation (EO) satellites. Since the 1980's, Sodern has played an active role first in the SPOT program. Within the two-spacecraft constellation Pleiades 1A/1B over the next years, Sodern introduced advanced technologies as Silicon Carbide (SiC) focal plane structure and multispectral strip filters dedicated to multiple-lines detectors. More recently, Sodern is participating to the OTOS technological program of CNES, preparing the future generation of very high optical EO mission, such as THR NG.

The main building blocks of focal plane are a highly stable structure and embedding detector modules with spectral capabilities. The architecture design is mainly driven by the mission parameters and detector features. The high spatial resolution with the ability to discriminate between small objects has been a major requirement since the early days of remote sensing. And in parallel, there was actually the need for wide swath coverage. The overwhelming trend is, therefore, the design and development of a very large focal structure with a large amount of customized detector modules with high data rate front end electronics and great performances.

This paper describes the results of activities managed by Sodern and gives an overview of the design and technology studies performed, including AIT (Assembly Integration and Test) process. The following items have been investigated and will be discussed: implementation of multispectral strip filter assemblies on next generation time delay integration (TDI) multiple-lines CCD or CMOS detectors, use of large SiC structure and the electronic interconnection with the use of Land Grid Array (LGA) instead of Pin Grid Array in the previous Pleiades detector package. Operating periodically on the orbit, the focal plane must cope with large variation of detector module power dissipation while obtaining good image quality performance and maintaining tight co-registration. A very low contamination throughout its assembly process and lifetime is also mandatory. Moreover, it has to stay within a critical mass budget and a total allocated volume.

II. MULTISPECTRAL STRIP FILTER ASSEMBLIES

CCD and CMOS detectors are inherently monochromatic with a spectral range covering the visible and near-Infrared parts of the spectrum (VNIR). So, filters need to be used in combination with multiple linear arrays to record images in the required spectral bands with for example 4 bands on Pleiades focal plane [1] and 10 bands on VNIR Sentinel-2 focal plane.

Earth remote sensing projects are constantly evolving and the demands are growing on multispectral (XS) filters with competitive cost and lead time without sacrificing performances. Sodern's multispectral filter assemblies address applications that require complex filter coatings with low defects and maximum stray light and crosstalk reduction. They are available in a variety of shapes and sizes and customized for matching the multi-linear detector features and the incident optical beams.

Fig. 1 shows the Sodern's basic design approach. Moreoften, for stray light mitigation purpose, Sodern proposes implementation of optical slit aperture masks on both sides of the optical plate. Similarly thin film coatings are also distributed over the two sides. But we are also able to create the best possible option taken into account the application specificities.

Fig. 1. Four stripe assembly concept (left) and straylight paths in an elementary stripe (right)

This design requires perfect manufacturing of optical wafers with appropriate coating deposition processes and the controlling of the opaque masks location during the lift-off process. The thin film deposition process is defined in conjunction with thin film candidate materials. The focus are on achieving high optical throughput and minimizing reflection losses. The goal is in this way to decrease the ghost image contribution in particular with the detector chip when the incident light hits the detector and reflected back toward the filter.

Improving spatial uniformity is another concern for stripe filters, and becomes all the more important so due to the ever increasing length of detector chip. For this, magnetron sputtering [2] is a very consistent deposition process that gives superior uniformity and is well suited for narrower bandpass filters around 20 nm.

After wafer manufacturing the following processes require sophisticated and perfect technologies which determine the final accuracy of the assembly and the cosmetics aspect. For this purpose, during multispectral filters assembly manufacturing, Sodern employs different capabilities in our air-conditioned manufacturing unit as a fully automatic dicing saw for wafer cutting, stripes bonding, adjustment production tools, automated mapping and defect sizing inspection machines. Taking advantages of our experience and automatic processes the lead time is shorter and compatible with more volume applications for instance when few detection modules are used for one focal plane retina. It also contributes to the improvement of the geometrical positioning of the different stripe slit apertures with an accuracy of about 10 μm from each other.

All of this proved to be a great benefit during the manufacturing of more than 120 flight models over the last five years at Sodern premises. A flight model component is shown Fig. 2. This Sodern's concept has flight heritage and established position with high resolution satellites providers.

Fig. 2. Side toward telescope with specular reflective mask (left) and toward detector chip with black mask (right)

II. DETECTION MODULE

The development of visible and near infrared detector modules is in the core business of Sodern since the beginning of the SPOT earth observation program during the eighties. More recent individual detection modules are shown Fig. 3. The photos give close-up of the spectral filters over detectors.

Fig. 3. Pleiades multispectral module (left) and CBERS multispectral module (right)

From the start of the focal plane conception the main driver is the modularity. This approach leads to define an elementary brick which is the detection module. Therefore the detection module is a complex package that consists of the detector, the dedicated multispectral filter assembly with mount, the Silicon Carbide SiC mechanical frame and optionally the associated front-end electronics including flexi-cable with connector. The main design drivers of the detection module are the high stiffness, the outstanding thermal stability taken into account the evacuation of detector dissipation while keeping a reasonable total weight. Moreover a possible replacement of a failed element in a reasonable timescale must be possible.

The way forward for future focal plane architecture is defined and confirmed through analysis and results obtained with demonstrator models or components developed on the last two years. The common denominator of all the activities is the objective of miniaturization.

The manufacturing of much larger overall focal plane size, ensuring the coverage of a wide swath over the ground, is achieved by abutting of multiple detection modules. There is one further point to bear in mind which is the implementation within a same focal plane of parallel cross-track linear retinas corresponding to imaging different lines on ground, for instance panchromatic (PAN) and multispectral (XS). On Pleiades illustrated Fig. 4, the detection modules are very close together with offset from each other since they cannot be superimposed. The use of mirrors in the Pleiades example was the answer to overcome the incompatibility between the size of the detection modules and the needs of separation between the detection lines. The miniaturization leads to simplify the focal plane arrangement with a far better staggered positioning of detection modules with overlapping within one retina and minimization of the offset between retinas. Furthermore, the miniaturization induces the removal of the central mirror and butting mirror that are needed on Pleiades and allows moving towards detector module staggered within a mosaic configuration focal plane.

Fig. 4. Pleiades focal plane arrangement by abutting multiple detection modules with five detectors per retina
Physical detector modules (left) and images of detector modules with mirrors (right)

Considering the length between 80 and 100 mm of current detector chip, the goal is to reduce the gap, or clearance area around the chip, between the edge of the silicium chip and the detection module envelope in the order of 1 cm instead of few centimetres in the projects mentioned in Fig. 3.

During focal plane studies, it was noted that the suitable detection module package size has been derived starting with the detector manufacturer design. Appropriate detector package interfaces facilitate the optimization and the along track direction, corresponding to the staggered positioning and offset values, is more critical whereas the overlapping value in the length direction is less critical due to the improvement already seen on the detector package alone.

This miniaturization is made possible by two substantial progresses or major breakthroughs. The first one is the removal of the glass lid on the ceramic detector package and the second one is the improved sealing method of the module cavity instead of the original bonding technology.

Removal of detector glass lid is also conducive for ghost image mitigation and it was another reason to its suppression. An optical window is commonly glued to flat surface on the periphery of the package and the sizing of the bond width was in the order of 4 mm that is disadvantageous for the package envelope. This removal nevertheless induces a growing concern with particle generation and dust contamination leading to even greater constraint on inspection and cleanliness procedure and clean room facilities during assembly processes as described chapter III.

The sealing method of the detection module package is a key enabling technology [5]. The first approach, that is the one applied in the recent developments, is to close the module package with a screw support that maintains the multispectral filter in front of the detector chip so that the adjustment is easy and the disassembly is still possible. The challenge in this case is to be compliant with the objective of miniaturization and to be able to correctly protect the chip from pollution. Specific solutions have been designed to have a ventilated cavity that avoids trapping molecular pollution and, at the same time, stops the entrance to the particules.

For the future detection modules, Sodern is also currently investigating an innovative assembly technology that presents the advantages of bonding, and of the inorganic concepts. This technology named Solderjet® Bumping developed by the Fraunhofer IOF institute is based on room temperature soldering. The photos Fig. 5 give some example demonstrators; silica lens in a titanium mount, a BK7 mirror on an aluminum base plate and a sealed window.

Fig. 5. Sealing method

Besides opto-mechanical activities Sodern also supplies front-end electronics as shown Fig. 6.

Fig. 6. Pleiades front-end electronics (left) and example of interconnexion of Pad Grid Array (PGA) on ceramic package (right)

Sodern is currently investigating the latest generation of detector with the higher operating frequency that induces higher level of integration for the preamplifier of the front-end electronics. The other concern is the new kind of ceramic package electrical interface with Land Grid Array (LGA) instead of via a plurality of pins (Pin Grid Array or PGA). Interconnection with hyperboloid contact technology satisfied the requirement for pin interface but is no longer suited and therefore we are investigating a new interposer architecture.

Some prototypes of this new interposer presented on Fig.6 have already been tested and show promising results. They are especially well fitted for LGA ceramic modules with a high density of contacts, a low thickness and also a long contacts stroke ($> 400 \mu\text{m}$ on each side).

II. LARGE SiC STRUCTURE

The support structure must be lightened while allowing sufficient stiffness of the assembly. This support structure must also be defined so as to minimize the detector chip temperature variation and to be compatible with the dimensional stability requirement in order to maintain pixel positioning.

The Silicon Carbide material is chosen for the main part of the structure thereby helping an efficient thermal coupling with the detection modules. Nonetheless, in comparison with Pleiades focal plane thermal braids and mechanical mount, the Silicon Carbide conductivity is insufficient and therefore additional heat pipes are investigated through a demonstrator model for future large focal plane developments. And moreover three kinematics Invar bi-pods are required for supporting the focal plane with the telescope.

The future goal is the reduction of the structure weight facing the new challenge of the focal plane total allowable mass and the volume constraint. This objective can be obtained through better modeling and forecasting tools and adequate stiffeners in select areas. In comparison with space mirror [3] the analysis is more complex due to the detection modules fasteners and the high fluctuation of thermal dissipation of detector plus front-end electronics with respect to satellite orbit. The photos Fig. 7 gives close-up of the new structure stiffeners when compared to Pleiades structure designed almost 10 years earlier.

Fig. 7. Pleiades focal plane structure (left) and example of local lightening ability in a SiC structure (right)

III. ASSEMBLY AND INTEGRATION

The quality of focal planes depends not only on the quality of the components, but also strongly on the quality of the assembly and mounting of the different components. And consequently the tools and test setup are of vital importance for the assembly and integration of focal planes. The main difficulties are the stringent alignment and positioning geometrical requirements in relation to mechanical reference frames.

For final assembly and integration of detection modules and focal planes several coordinate measuring machines are operated in a dedicated 40 m² clean room ISO-5 or in specific ISO-5 zones as shown Fig. 8. By precisely recording the coordinates of pixels or pattern recognition marks commonly called fiducial marks, locations are measured and effective retina shape is extracted and adjusted by regression. The locations are repeatedly measured by an operator or automatically via direct computer control in order to assess the stability prior and after environmental tests.

Fiducial marks can be attached to delicate object as detector package or optical windows or directly implemented on components during optical thin film coating deposition using a lift-off process that is on the chip or on the filter. Sodern has defined several kinds of fiducial marks with high contrast for automated recognition and accurate placement on machine vision based as crosshair reticle or round tag. Few examples are given Fig. 9.

Fig. 8. 3D coordinates measuring machine with optical and mechanical probes – Measurement capacities: 300 mm x 200 mm x 200 mm on the left and on the right a 1m³

Fig. 9. Example of fiducial marks on components. Cross shape mark on 1 mm x 1 mm glass blocks (left) and new kind of fiducial marks under evaluation for high accuracy measurements

III. CONCLUSION

Recent activities with the manufacturing of demonstrator models and components were made possible by the funding coming from CNES in the frame of French Earth remote sensing R&T programs. A number of new key features and improvements have been introduced.

All of these demonstrators give useful information about the critical issues to be particularly addressed in the frame of a new program. Moreover substantial improvements are also identified for missions based on constellation of satellites where competitive cost and lead time reduction are of prime importance.

IV. ACKNOWLEDGEMENTS

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