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Technological development of multispectral filter assemblies for micro bolometer

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***Abstract*—** Since 2007 Sodern has successfully developed visible and near infrared multispectral filter assemblies for Earth remote sensing imagers. Filter assembly is manufactured by assembling several sliced filter elements (so-called strips), each corresponding to one spectral band. These strips are cut from wafers using a two dimensional accuracy precision process.

In the frame of a 2011 R&T preparatory initiative undertaken by the French agency CNES, the filter assembly concept was adapted by Sodern to the long wave infrared spectral band taken into account the germanium substrate, the multilayer bandpass filters and the F-number of the optics.

Indeed the current trend in space instrumentation toward more compact uncooled infrared radiometer leads to replace the filter wheel with a multispectral filter assembly mounted directly above the micro bolometer window. The filter assembly was customized to fit the bolometer size. For this development activity we consider a ULIS VGA LWIR micro bolometer with 640 by 480 pixels and 25 microns pixel pitch. The feasibility of the concept and the ability to withstand space environment were investigated and demonstrated by bread boarding activities.

The presentation will contain a detailed description of the bolometer and filter assembly design, the stray light modeling analysis assessing the crosstalk between adjacent spectral bands and the results of the manufacturing and environmental tests (damp heat and thermal vacuum cycling).

Keywords; *Remote sensing, Optical filters, Multi-spectral strip filter assemblies, Infrared radiation*

I. Introduction

Through new projects, such as MISTIGRI (MIcroSatellite for Thermal Infrared GRound Surface Imaging), the CNES in France promoted the monitoring of water cycle and energy exchange in ecosystems. The MISTIGRI instrument records several spectral channels in the Long-Wave InfraRed (LWIR) at 50 m high resolution with micro-bolometer uncooled solution.

In this context and thanks to our developments of VNIR multi-spectral strip filter assemblies, the CNES expressed their interest of the strip filter assembly technique for this infrared application.

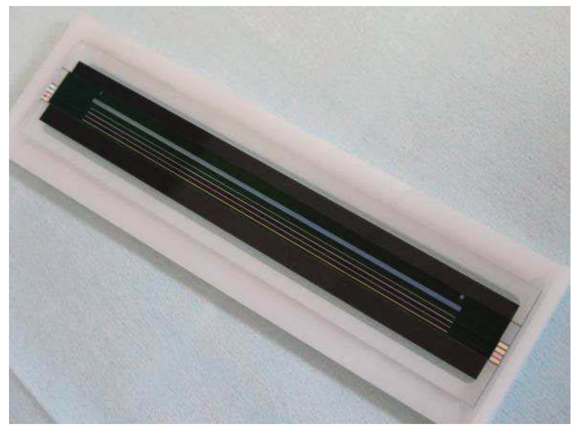

Figure 1. VNIR multispectral strip filter assembly

Sodern has demonstrated the versatility of this VNIR filter assembly technique which offers high radiometric performances and low defects density and size. This technique also eliminates the need for complex patterning flowchart. Sodern provides custom engineering support from design through final assembly with thin film deposited on elementary wafers. The first flight models were delivered to ASTRIUM for export NAOMI cameras as depicted figure 1 and [3].

Besides this optical filter activity and since year 2000, Sodern has developed several infrared imagers with today 2 models still flying in orbit, one on IASI instrument on board METOP satellite and the other one on board CALIPSO satellite in the A-Train experiment. Each imager is equipped with uncooled micro-bolometer arrays.

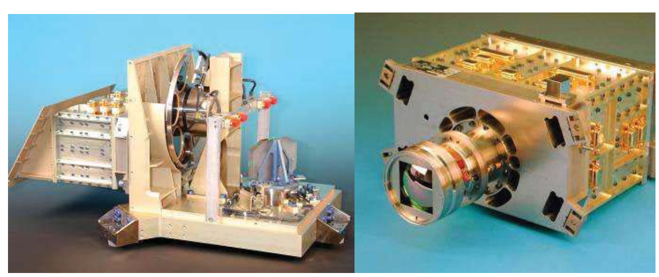

Figure 2. CALIPSO (right) and IASI (left) imagers

This work was supported by the French Centre National d'Etudes Spatiales (CNES).

II. PROPOSED ARCHITECTURE

A. Instrument Overview

The MISTIGRI architecture briefly presented hereafter is the result of technical studies and trade-off led by CNES. For details, the reader can refer to paper [2]. The multispectral pushbroom imager, sensitive to the 8.6, 9.1, 10.3 and 11.5 microns regions, provides surface radiometric temperature and emissivity.

The Focal Plane is based on a single uncooled micro-bolometer VGA array of 640 (cross-track) x 480 (along-track) with a pixel pitch of 25 microns developed by French company ULIS. The Time Delay Integration (TDI) algorithm is applied to improve the NETD performance by summing around 30 independent spatial measurements of each line on the ground.

B. Focal Plane Overview

The multispectral filter assembly is depicted figure 3. The filter is manufactured by assembling four linear sliced filter elements purple in this picture, so-called strips, each corresponding to one spectral band. The strips are bonded together side-to-side. These strips associated to one spectral channel are cut from one germanium plate over-coated with the required bandpass optical filter using a two dimensional accuracy precision process. The size of each stripe is approximately 15(l) x 3.5(w) with a thickness of 1mm.

Next the filter assembly will be integrated close to the bolometer window, i.e. around hundred microns, as seen figure 4. The filter assembly will be first assembled into a structural housing with two lateral bezels and then bonded on the bolometer package thanks to specific alignment techniques. Small labyrinthine vents between bolometer window and filter will allow pressure equalization during lifetime.

During this development activity, market off-the-shelf LWIR narrow bandpass filters were purchased. We selected two different coating suppliers offering appropriate performances, i.e. bandwidth and rejection, and providing solutions in applications where a severe environment is anticipated.

Figure 3. LWIR multispectral filter assembly

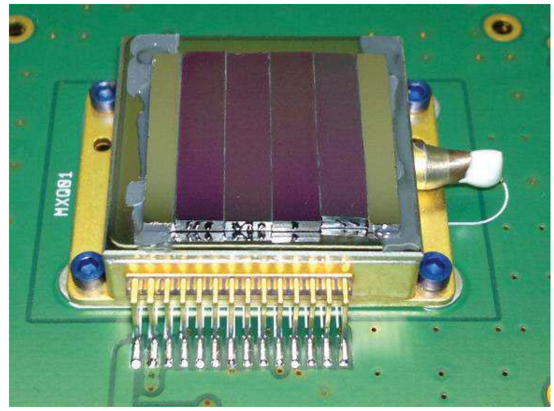

Figure 4. LWIR focal plane prototype

C. Ghost image analysis

The goal of this analysis was to predict quantitatively the amount and distribution of stray light that reaches the focal plane. The analysis was carried out with FRED® software.

For this study, since the filter assembly is in close proximity of the detector and with the relatively low f-number of the uncooled imaging system, the stray light is mainly caused by ghost image artifacts. The critical aspect was the optical crosstalk between neighboring bands.

Ghost images are produced by multiple-reflection (even number of times) of light on optical element surfaces. The magnitude of a ghost image depends upon the surface reflectivity (mainly the product of two reflectances: detector and bandpass filter) and the relative distances between optical surfaces which induce the out-of-focus and the lateral shift of the ghost image. The lateral shift is sensitive to misalignment, particularly to the tilt of the filter assembly parts.

Based on the modeling, the crosstalk level should not exceed 0.15% on the useful areas.

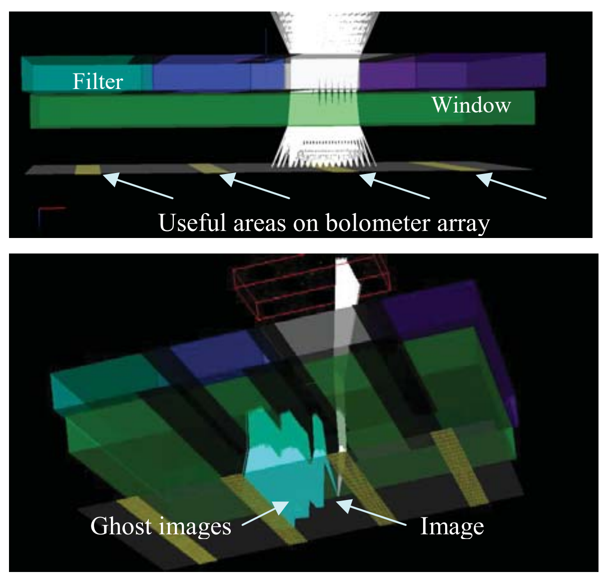

Figure 5. Ray tracing simulating the propagation of light

III. Manufacturing and Test Results

A. Filter Assembly Level

First the VNIR flowchart and the manufacturing processes were re-assessed since machining operations are more challenging on the germanium substrate which is more friable than glass. In addition the gluing process was adjusted and revalidated on representative samples.

We also validated the opacity of epoxy used between strips i.e. transmission less than 0.1% in LWIR.

Two representative prototypes of four-color LWIR assembled arrays were produced showing the good reproducibility of this technology.

During the manufacturing stage we found that strips are very sensitive and any physical contact will cause damage. Thus the delicate nature of the LWIR strips requires that special procedures be followed for handling and cleaning. By practicing two different coating manufacturers we also found that the supplier origin of one of the products is less fragile than the other one.

The current state-of-the-art in term of positioning and sizing features is given in the table 1 with the comparison with VNIR domain.

TABLE I. Positionaning and sizing features

Typical (4 bands in one device)	**Multi-spectral filter assembly**		
	Unity	***VNIR(a)***	***LWIR(b)***
Mechanical interface flatness	µm	< 10	< 30
Co-planarity on one side (filters useful areas)	µm	< 20	< 60
Stripe tilting versus mechanical interface	Deg.	< 0.2	< 0.1
Center-to-center tolerance cumulative over 4 or 5 bands	µm	< 10	----
Relative position (acroos-track)	µm	< 50	< 50
Dead zone between neighboring bands includind bond line width	µm	< 150	< 150
Strips thickness matching	µm	< 20	----

(a) with VNIR strip dimensions: (L x W x H) 100x1x1.5 mm

(b) R&T results before industrialization activities

Additional samples and witnesses were used during environmental test campaign.

One prototype was subjected to laboratory environmental durability tests that consisted of a combination of slow temperature change thermal cycles and damp heat.

The sequence included:

- Humidity 24 hours, 85°C ±2°C , 85% ± 10% RH
- 5 thermal cycles, [-25°C; 60°C], 15 min dwell time

Before and after each environmental test the co-planarity, the tilting and the center-to-center spacing between strips were measured to check the stability of the filter assembly design.

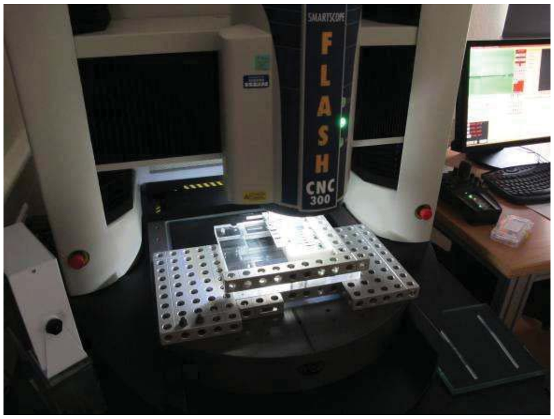

Figure 6. Filer assembly metrology tools

No significant defects in the useful areas were detected after visual inspection with automated optical inspection system.

And no positioning changes between strips, i.e. less than 2 microns, were measured by means of the use of three-coordinate measuring machine (figure 6).

B. Focal Plane Level

One prototype was produced see view on figure 4.

This focal plane assembly was then subjected to laboratory environmental durability tests that consisted of a combination of slow temperature change thermal cycles and damp heat.

The sequence, same as on filer assembly alone, included:

- damp heat 24 hours, 85°C ±2°C , 85% ± 10% RH
- 5 thermal cycles, [-25°C; 60°C], 15 min dwell time

In addition in order to establish any changes in the behavior of the prototype, radiometric tests were realized thanks to the following equipments available at Sodern premises:

- the bolometer video acquisition chain as shown figure 8. The characterization of this chain compliant with space environment requirements was supported by the CNES in 2011.
- and a test set-up dedicated to IASI and CALIPSO products acceptance tests shown figure 7.

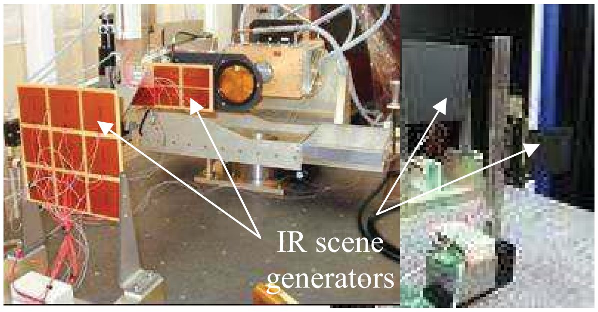

Figure 7. CALIPSO& IASI Imagers test set-up

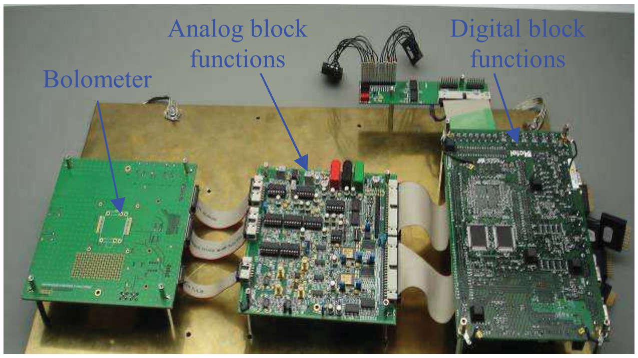

Figure 8. Bolometer video acquisition chain

The radiometric evaluation was accomplished with two extended area differential blackbodies with temperatures between 30°C and 100°C.

Corrections of bolometer drift and non-uniformity as offset correction for each pixel in the array have been considered with our electronics. The first stage of the analog front-end electronics provides signal amplification and differential subtraction of the pixel-to-pixel offset. Digitization is performed on 14 bits, for an effective resolution of 12 bits. On micro-bolometers, the fixed pattern noise (FPN) caused by pixel-to-pixel offsets can typically reach 1/3rd of the detector electrical dynamic range. The subtraction function is driven by a coarse 4-bit digital to analog converter working at the video data rate. The correction of pixel-to-pixel offsets reduces by 16 the signal amplitude variations induced by FPN, and allows using a high video gain in order to minimize the quantization noise when observing low contrast scenes as shown figure 9.

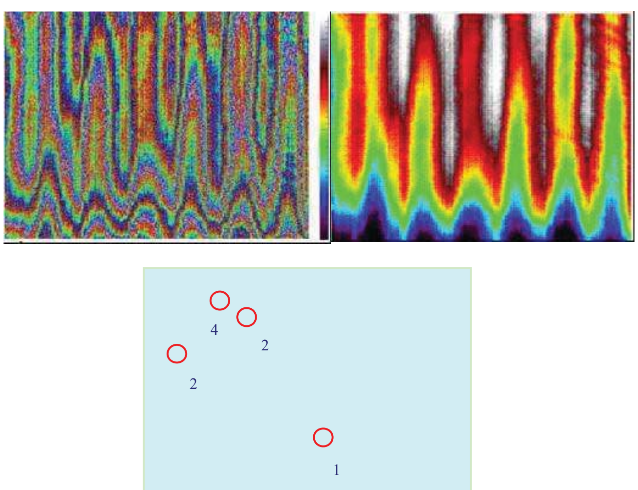

Figure 9. Flat field image before coarse FPN correction (right) and after correction (left). Nine pixels are significantly outside the normal distribution and were indicated as bad pixels.

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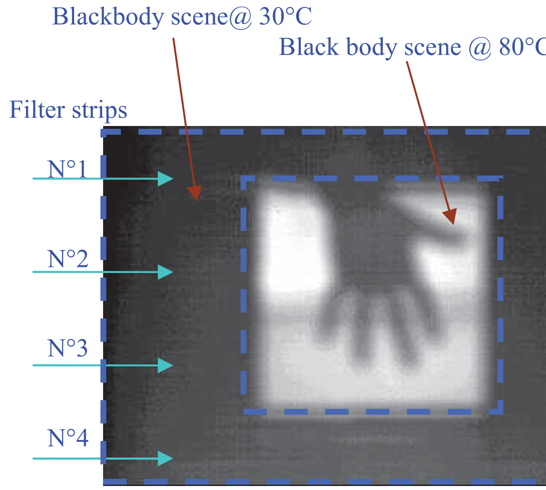

Figure 10. LWIR focal plane prototype

This uncooled focal plane enables the user to view a scene as depicted figure 10. Dead zones between neighboring strips bands including bond line width limits the field of view.

IV. Conclusion

Multispectral filters are always complex and need careful preliminary analysis in order to be successfully employed.

Initiated few years ago at Sodern, VNIR multispectral filter assembly technology has been proved to work under space environmental conditions. And some flight models were already delivered.

In the LWIR spectral domain the prototype has shown very attractive characteristics and performances. The evaluation proves that this technology works under expected space environmental conditions.

In conclusion, it is clear that multispectral filter assembly is a technique that will be essential for the manufacturing of pushbroom imager in the future. A lot of efforts are underway at Sodern to increase performances mostly in order to obtain better geometrical tolerances and higher cosmetic quality.

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