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## *VIS/SWIR IR detectors for space applications at AIM: models and qualification status*

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# VIS/SWIR MCT detectors for space applications at AIM: models and Qualification status.

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## ABSTRACT

AIM has developed IR modules including the FPAs for a wide range of applications. For SWIR applications FPAs based on liquid phase epitaxy (LPE) are available. These devices having different array sizes and are usable in a wide range of hyperspectral imaging applications. Silicon readout circuits provide various integration and readout modes including specific functions for spectral imaging applications.

An important advantage of MCT based detectors is the tunable band gap. The spectral sensitivity of MCT detectors can be engineered to cover the extended SWIR spectral region up to 2.5 $\mu\text{m}$  without compromising in performance.

AIM developed and released the technology option to extend the spectral sensitivity of its SWIR modules also into the VIS. This has been successfully demonstrated for different FPA designs. A short overview is given in tis paper.

AIM has qualified this VIS technology option based on a 1024x256 FPA capable for extended hyperspectral applications. Within this paper the test approach and the results will be presented.

**Keywords:** MCT, SWIR, Extended SWIR, VIS/SWIR, Hyperspectral Imaging, Qualification

## 1. INTRODUCTION

During the last decades AIM has established a fundamental competence for MCT based IR detectors from short wave to very long wave detection range. In the beginning these imaging detectors have been exclusively used in defensive industries, mainly due to classification as military goods and high costs of such devices. In recent years, this wide range of technology was used in space instruments too, while an increasing number of commercial and industrial applications was emerging using the standard SWIR spectral range from 0.9 $\mu\text{m}$  up to 1.8 $\mu\text{m}$ , as well as the extended SWIR spectral range up to 2.5 $\mu\text{m}$ . Hyperspectral applications are found to be the main driver for these instruments.

To satisfy these needs, AIM has developed a variety of SWIR detector modules. AIM has the advantage of having all necessary technologies for manufacturing of high performance MCT sensor modules and cameras under one roof. Large sized CdZnTe substrates are grown in-house. The photo-sensitive MCT-layers are formed by liquid phase epitaxy (LPE) and the PV-chips are subsequently hybridized to AIM-designed silicon readout integrated circuits (ROIC) via Indium bump technology to form focal plane arrays (FPAs). The FPAs are integrated into dewars and fitted with AIM manufactured Linear Stirling coolers. A high performance command and control electronics (CCE) allows digital interfacing and easy control of the so called Integrated Detector Cooler Assemblies (IDCA). The IDCAs are delivered to the customers, who integrate these into their systems for all kind of imaging and hyperspectral imaging applications. As these systems are very diverse, often customer specific modifications, e.g. different cold shield apertures (FOVs) and/or

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the integration of customer specific (cold) filters, are made. Furthermore, AIM does also manufacture fully integrated cameras for stand-alone imaging applications.

An important advantage of MCT based detectors is the tunable band gap. The spectral sensitivity of MCT detectors can be engineered to cover the extended SWIR spectral region up to 2.5 $\mu\text{m}$  without compromising in performance and thereby supersedes the accessible spectral bands of other sensor technologies, like InGaAs.

Some hyperspectral imaging applications require spectral sensitivity from VIS to SWIR spectral bands, which means 0.4 $\mu\text{m}$  to 2.5 $\mu\text{m}$ . Typically, this is realized by systems comprising different hyperspectral imaging sensors for VIS and SWIR in combination with beam splitters and multiple spectrometers. This adds significant complexity and costs to such systems. A combined VIS/SWIR sensor would allow realizing smaller sized, light weight and more cost effective hyperspectral imaging systems.

Having this in mind, AIM started efforts to push the usable spectral range of CMT further into the visible range. During the last years a technology option was developed in order to make the MCT detectors sensitive in the visible range. This technology was improved and fine tuned over the last years to achieve highly sensitive devices for the whole spectral range from 400nm to 2500nm. Several devices have been shipped as breadboard samples, engineering or QM devices for different hyperspectral applications. This technology option has in the meantime reached a maturity, for which it can be applied to any AIM SWIR detector format, enlarging the detector sensitivity into the visible range.

## 2. VIS TECHNOLOGY OPTION REVIEW

The MCT imaging detectors, which are the main stream of the AIM products, are typically build as hybridized arrays in conjunction with a readout IC (ROIC). In this configuration the MCT is illuminated from the backside. The photosensitive layer of the hybrid is the epitaxial layer of the MCT detector element, which is grown on a substrate, which is matched from the crystalline behavior but should be much cheaper. For this reason CdTe substrates are widely used, which allows a high quality growth of the MCR detector layer. The drawback of this solution is the fact, that the optical characteristic of this substrate is dominating the performance of the detector. A large fraction of the MCT detector still remains on the device, located between the illumination source and the sensitive area. This substrate is blocking the visible bands from approximately 800nm to shorter wavelength, acting as a high pass filter.

The simple solution for a VIS option is to remove this blocking layer. For the technology implementation this was found to be quite challenging, since a lot of interactions and critical conditions have to be respected. However, these issues are well under control now, the sketch of the AIM FPA with VIS/SWIR option is given in Figure 1. The final MCT detector layer is mainly build by the epilayer itself without residual substrate material. The surface is passivated and coated with a multilayer anti reflective coating ensuring a minimized photon loss due to reflections over the whole spectral range.

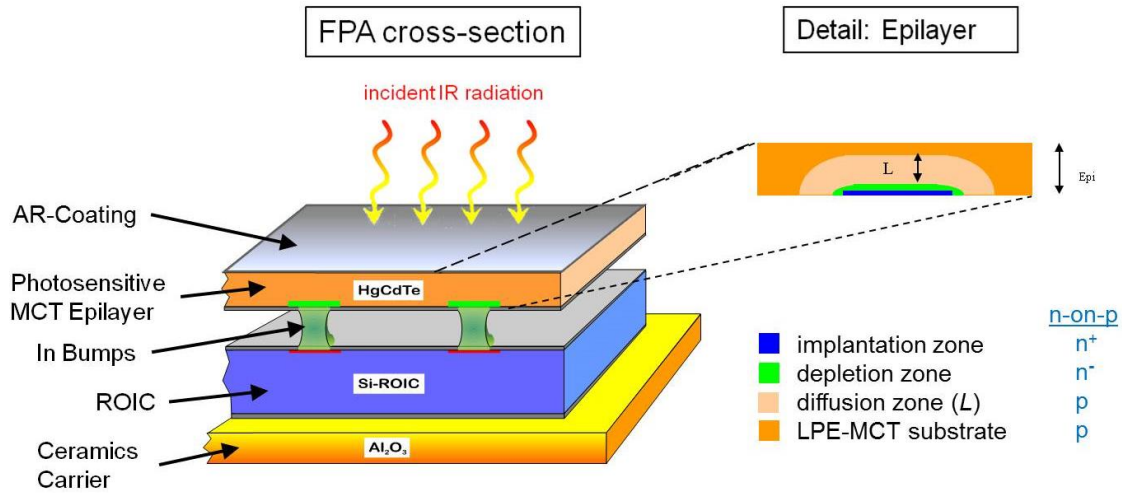


Figure 1: Schematic cross section of VIS/SWIR focal plane array.

The resulting device is sensitive in the visible spectral range, the electro optical performance was tuned to be as much as possible homogenous across the whole wavelength range. A typical result for this device is given in Figure 2.

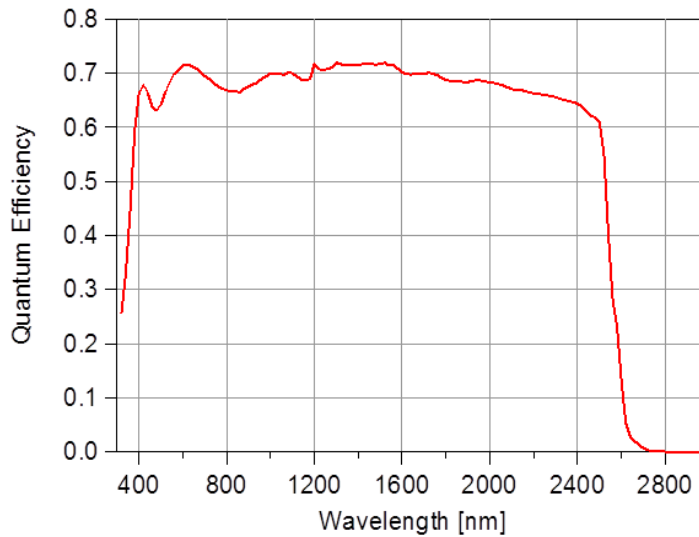


Figure 2: typical spectral QE behavior of an AIM VIS/SWIR detector.

In this configuration an RGB picture can be directly assembled from three separate pictures with selected bandwidth while the SWIR capability is still giving an image in the infrared range (Figure 3).

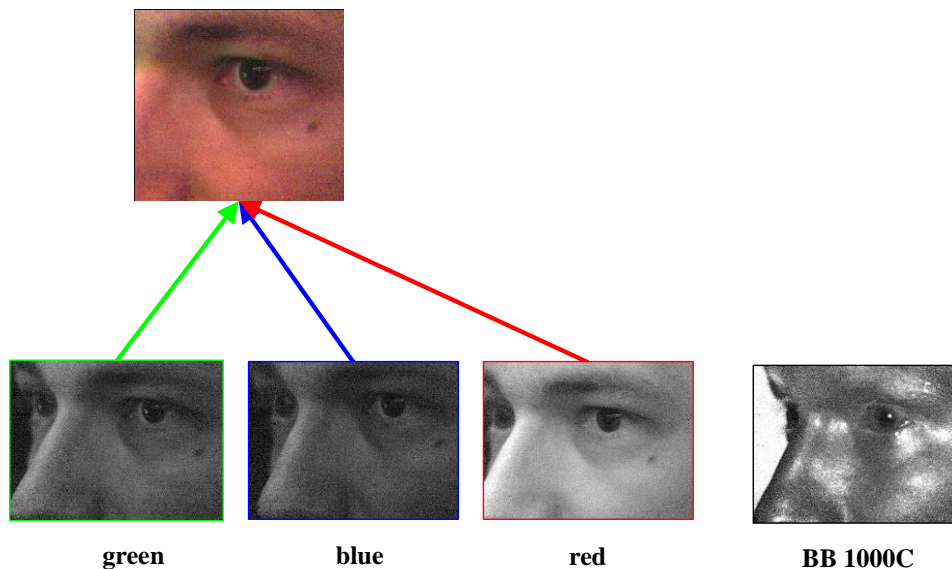


Figure 3: VIS/SWIR imaging options.

### 3. SWIR IMAGING SENSORS WITH EXTENDED CUTOFF

Through the years several detector arrays have been processed and shipped using the VIS/SWIR option. They are described in [1] and sketched below.

#### 3.1 MCT 384x288 SWIR Module

The MCT 384x288 SWIR module with MCC030 Single Piston Cooler is a compact module with a spectral band of  $0.9\mu\text{m} - 2.5\mu\text{m}$  without the VIS option and  $0.4\mu\text{m} - 2.5\mu\text{m}$  with the VIS option. Using state of the art detector and cooling technology [2] the device provides high sensitivity and a long life time (life time cooler  $> 25000\text{h}$ ) for 24/7 industrial applications. Easy system interfacing is achieved with its fully digital output. High frame rates up to 450Hz full frame imaging provide outstanding performance.

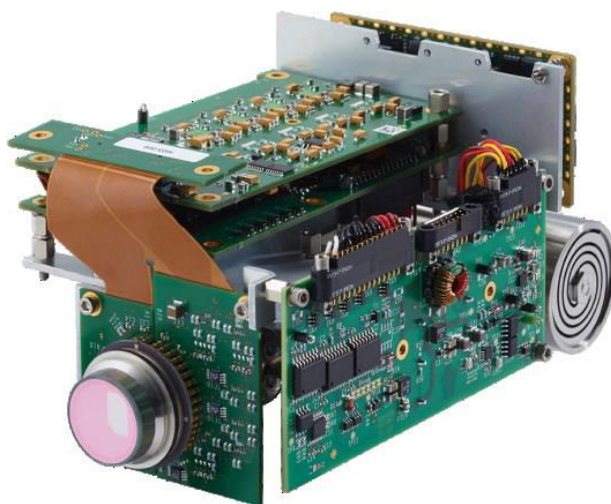


Figure 4: MCT 384x288 SWIR module with MCC030 Single Piston Cooler.

### 3.2 MCT 640x512 SWIR Module

The MCT 640x512 SWIR modules with a pixel pitch of  $15\mu\text{m}$  comprises an optimized ROIC design with further improved noise performance and dynamic range parameters. In contrast to the 384x288 and 1024x256 ROICs designed for a wide range of photon flux conditions, the 640x512 SWIR ROIC is designed for operation under low light level conditions mainly for the use in imaging systems. Under low-light imaging conditions, the ROIC is used in the rolling shutter mode with Correlated Double Sampling (CDS). CDS helps to reduce the readout reset noise by sampling the reset signal level just after the pixel reset. By subtraction of this reset level value from the signal obtained after the full integration time, the kTC-noise of the CTIA input stage can be cancelled or at least reduced. Thus, the readout noise is significantly reduced as compared to the standard snapshot modes using no CDS. This module is available with and without SWIR option.

The next generation of this array has been developed for SWAP application. It comprises a FPA with  $10\mu\text{m}$  pixel pitch, which is available with the VIS option too.

### 3.3 MCT 1024x256 SWIR Module

The ROIC of the MCT 1024x256 SWIR module has a similar architecture and therefore offers the same features and similar electro-optical performance as the MCT 384x288 SWIR module. Also, the user interfacing has been designed identical. Compared to the 384x288 SWIR module, the MCT 1024x256 SWIR module with SF100 Pulse tube cooler provides a much longer detector row (1024 pixels) in combination with an extreme long lifetime cooler (lifetime  $> 50000\text{h}$ ). The long detector row is beneficial for pushbroom-like applications such as airborne hyperspectral imaging, because it allows coverage of a larger ground area with less flight tracks. Although the much larger detector area, the module still allows reasonable high framerates of up to 250Hz in full frame mode. The pixel size of  $32\mu\text{m} \times 24\mu\text{m}$  is slightly larger, which also allows a slightly higher storage capacity (CHC) in low gain mode.

Figure 5 depicts a VIS/SWIR QM with provided for a pre-study of a hyperspectral flight application. This device is assembled with a high reliable SF100 pulse tube cooler (not shown in the picture) and dedicated interface of a custom heat sink, which makes it operable also under vacuum conditions.

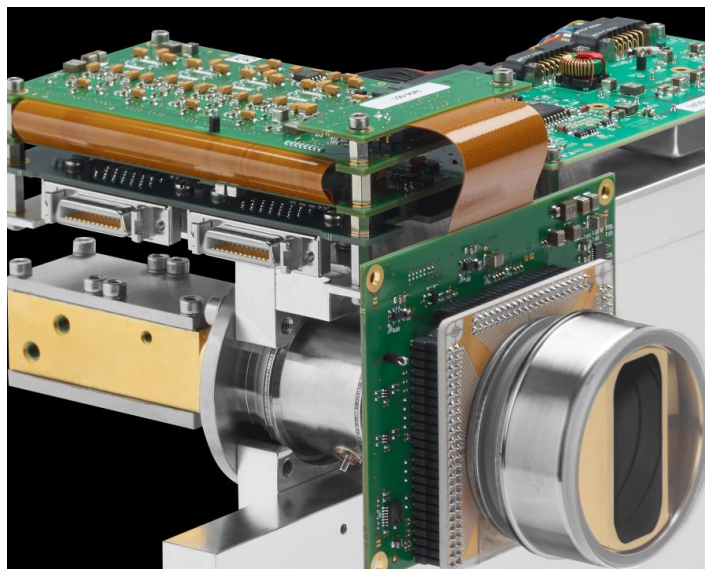


Figure 5: MCT 1025x256 VIS/SWIR QM module with SF100 pulse tube cooler and electronics.

## 4. QUALIFICATION SET UP

### 4.1 Objectives of the qualification

The possible applications of this kind of VIS/SWIR detectors are manifold. As an initial and driving force the hyperspectral imaging is the main application, but the usability is not limited to this area. The hyperspectral applications can be found in the industrial area as well as in military applications and for space missions. For this broad spectrum of applications and requirements an all-embracing qualification is out of scope. Therefore this qualification was focused on the relevant differences to the mainstream devices, which are qualified under their specific requirements. The environmental tests are mostly excluded, since they are usually relevant for the dewar assembly and the electronics. For space application the radiation tests were excluded too, since there was no extended risk indication for the MCT from the already radiated devices in other AIM space programs. Furthermore, the radiation test is usually required in the final assembly, so a full radiation test campaign with existing devices would be no more than indicative.

Therefore the qualification was set up to cover the most common requirements related to the applied modifications:

- Changed sensor layer thickness due to removal of the substrate
- Adjusted ARC layer to match the widened spectral band

After an assessment on the possible degradation mechanisms the following issues were elaborated:

- Mechanical performance:

The thickness of the hybridized layer is changed. With the known mismatch of the CTE values for the ROIC and the MCT this will change the internal stress in the FPA too. This impact will be mainly effective in the thinner MCT material, which inherits the risk of mechanical overstress resulting in broken MCT material.

A second mechanism is related to the ARC. Since this layer had to be modified too, the long term stability against delamination has to be proven.

- Electrical performance:

The MCT space charge region as the light sensitive detection layer is now near the mechanical surface, having a new surface coating with respect to the SWIR baseline. Electrical fields can impact the detection sensitivity. Effect may be enforced by continuous biasing and debiasing of the MCT diodes.

- Optical performance:

With the near surface location of the space charge layer of the MCT detector, any degradation on the mechanical interface can impact the detection efficiency of the device. Degradation of the ARC will be visible in the QE and can be taken as a very sensitive indicator for device stability.

A test procedure covering the given objectives is described in the following chapter.

## 4.2 Test procedure

As test device a 1024x256 pixel detector having a MCT active area of  $24.6 \times 8.2 \text{ mm}^2$  was selected for the qualification. This is the largest detector size which has been processed with the VIS option. For these dimensions the mechanical stresses will be maximal, representing the worst case condition for the mechanical properties.

This device was assembled into a laboratory dewar, which is comparable to an available device but not constantly under vacuum condition. The front cover is not fixed to the main housing. This allows a quick access to the detector hybrid, but it needs to be constantly evacuated during the tests (Figure 6).

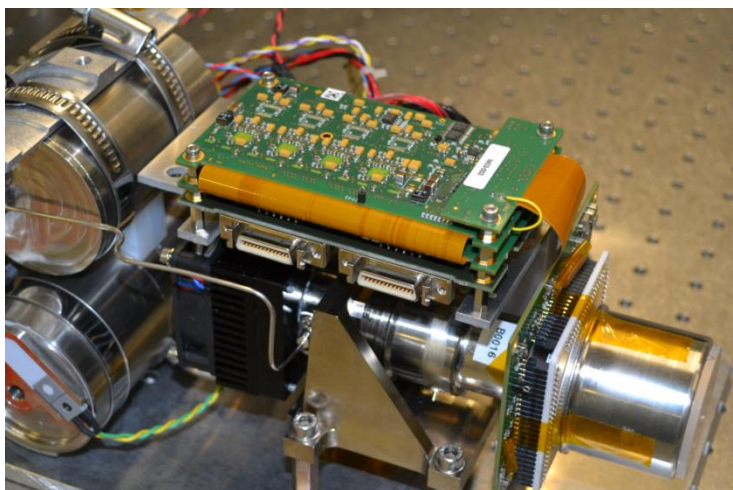


Figure 6: Test assembly with SF100 pulse tube cooler, buffer volume and electronics.

This assembly was mounted in front of a optical sphere, where the electro optical characterization was made (Figure 7). During the whole test the device remained fixed before the sphere in order to get the most reproducible test conditions before and after the thermal cycle stress.



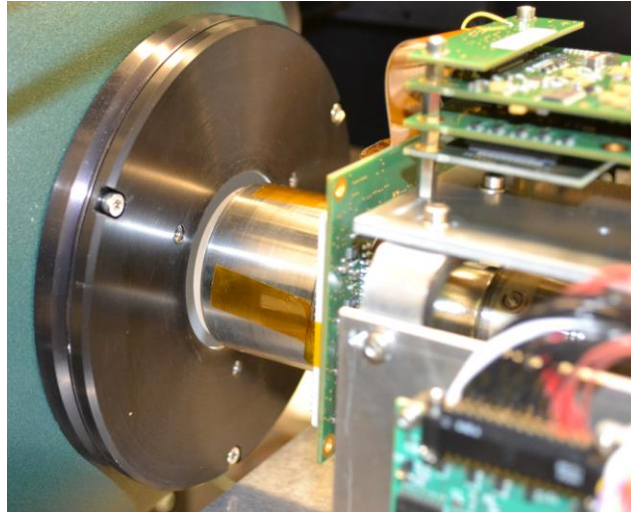


Figure 7: Set setup in front of the optical sphere.

To ensure the most reproducible spectral analysis, the spectral verifications were done using band pass filters mounted in the sphere. By this approach any uncertainty related to a mechanical handling and adjustment to a spectrometer is excluded. The available filters for the spectral test are listed in Table 1. The reference curve taken in this configuration is given in Figure 8.

Table 1: Center wavelength and bandwidth of the test filters.

<b>CW</b>	<b>BW FWHM</b>
405nm	10nm
510nm	10nm
610nm	10nm
1000nm	10nm
1300nm	10nm
1510nm	12nm
2200nm	12nm

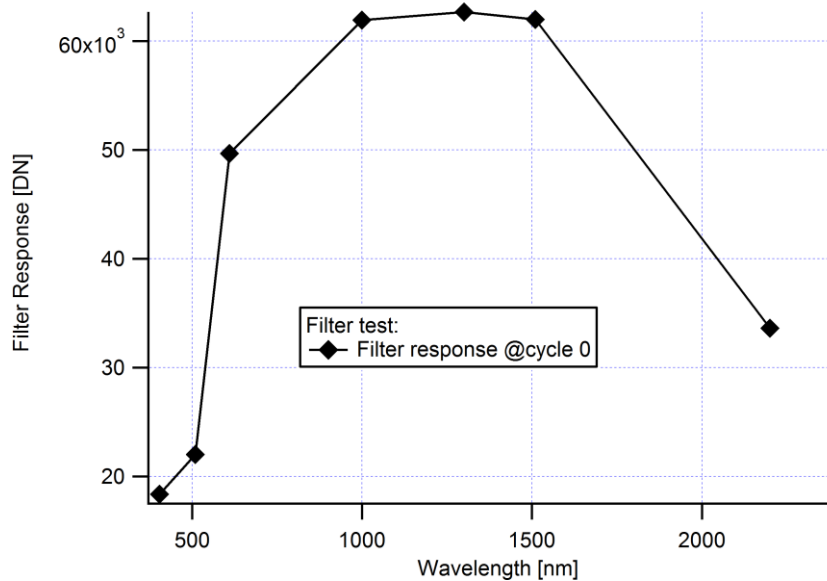


Figure 8: Spectral reference tests using the filters mounted in the sphere.

The mechanical and electrical stress is generated by combined electrical and thermal cycles. One cycle is defined in the following way:

- Cool down to operating temperature (150K), switch on the FPA
- Stabilisation for 10 minutes
- Dark measurement
- Switch off cooler and FPA
- Temperature ramp up for 40 minutes to approx. 290K (representing room temperature)

The whole qualification procedure was defined in the following way:

- Visual inspection, electro-optical pre-characterization in sphere
- Temperature cycle test with minimum 1000 cycles
- Electro-optical post-characterization in sphere, visual inspection

## 5. TEST RESULTS

The presented results are based on a test run which comprises 1018 combined thermal and electrical cycles. For each cycle a measurement was made, a sample picture representation of the signal and noise level is given in the Figure 9 and Figure 10.

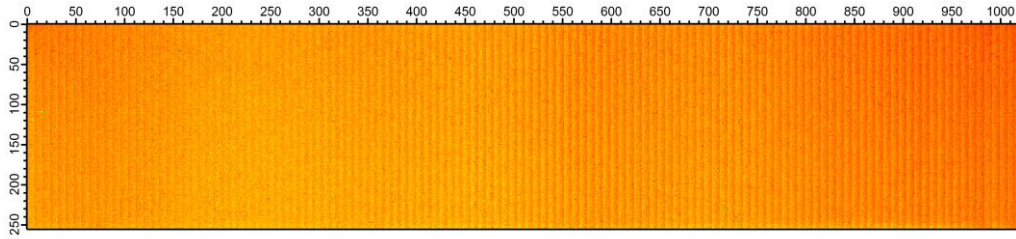


Figure 9: Sample signal image of test cycle measurement.

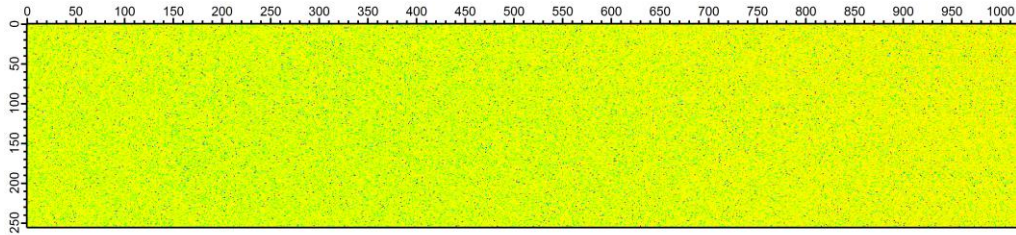


Figure 10: Sample noise image of test cycle measurement.

These measurements have been analyzed; they are showing no deviation over the time. It was noted, that for a weekend the temperature control of the test laboratory was not working. This resulted in a drift of the room temperature of 2°C and an offset shift in the test electronics. This shift is the root cause for the peak in the signal histogram at 3746 DN and some increased noise levels. Except this event the test run without further distortions. The test spread of the signal and noise value is depicted in Figure 11 and Figure 12. The test results are listed in Table 2.

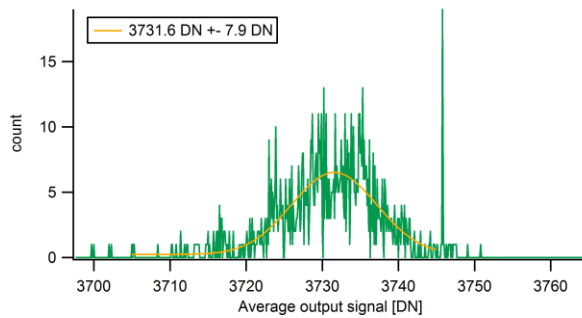


Figure 11: Histogram of cycle test signals.

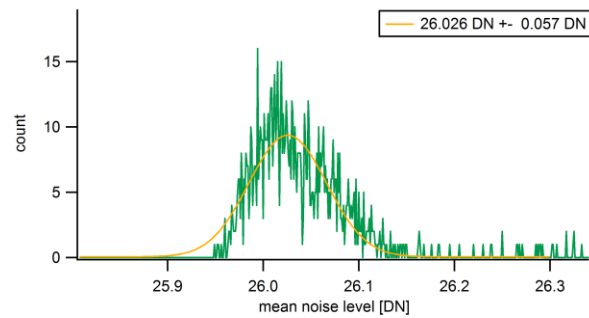


Figure 12: Histogram of cycle test noise.

Table 2: Summary of dark signal tests.

Parameter	Mean value [LSB]	Variation [LSB]	Variation [e-]
Signal level	3731,6	7.9	55
Noise	26.026	0.057	0.4

For the spectral analysis the reference curve with different filters was repeated. The broad band reference measurement showed an increased signal by 0.3%. This level shift was found for all filter measurements too and can be taken as variation of the source intensity (Figure 13). After compensating this impact the measurement results are found the same, no sensitivity shift was detected.

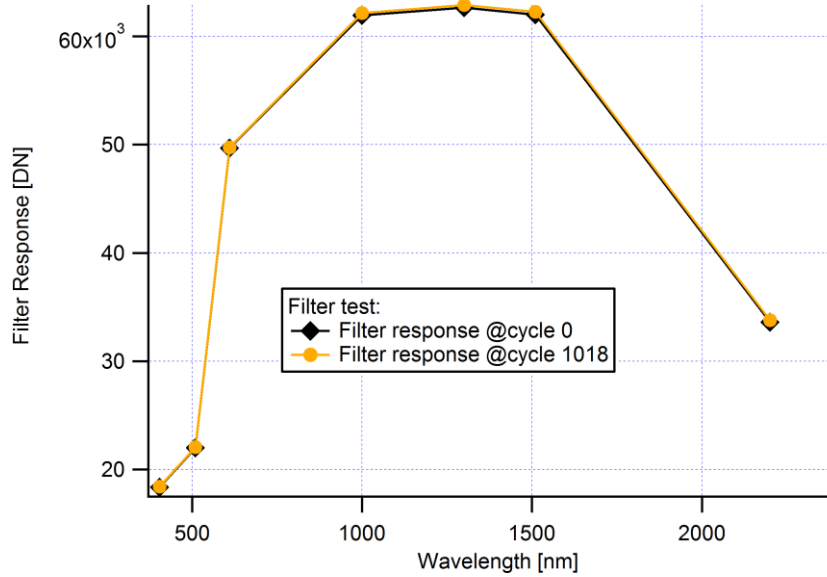


Figure 13: Comparison of spectral measurements before and after thermal cycling.

At the final visual inspection no mechanical degradation was found. The device was damage-free. No fracture was found, no delamination was observed. Even in the corner of the device, where the mechanical stress will be maximize, the MCT and ARC layer remained unchanged (Figure 14).

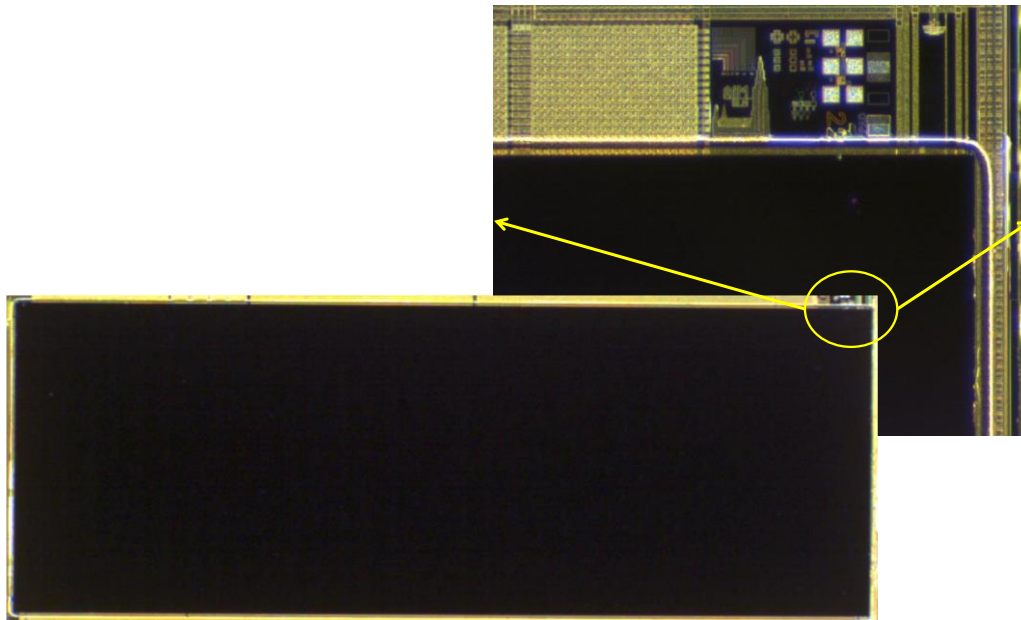


Figure 14: FPA overview with detailed highlight of a corner.

## 6. CONCLUSION

A qualification test was set up to validate the stability of the AIM VIS option for their SWIR IR detectors. The Qualification was set up as delta qualification, focusing on the most common requirements for industrial, military and space applications.

For this approach a temperature cycle test with 1018 test cycles was performed on a 1025x256 pixel VIS/SWIR detector, combining temperature cycles between 150K and 290K with electrical switch on/switch off cycles.

Electrical and optical data collected during this campaign showed excellent stability of the detector without a degradation trend. The spectral sensitivity remained unchanged.

No impact of the thermo-mechanical stress was found. The MCT material as well as the ARC layer were found stable and defect free. No delamination was observed.

With these results a basic qualification was achieved covering the most important qualification steps for a broad range of high reliability applications.

## REFERENCES

- [1] Breiter, R., Benecke, M., Eich, D., Figgemeier, H., Weber, A., Wendler, J., Sieck, A., "MCT SWIR modules for passive and active imaging applications", Proc. SPIE 9819 (2016).
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