Invited paper

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High resolution staring arrays answering compact MW and LW applications

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This paper overviews the electro-optical and thermal performances of different types of infrared detectors manufactured by Sofradir. The detector's fabrication processes and detector's performance are shortly described. New staring arrays are more compact and offer system solutions required by infrared market. Special attention is directed to some reliability advantages of new dewar design. Finally, the development trends for highest resolution infrared detector are discussed.

Keywords: infrared detectors, third generation, Sofradir, HgCdTe, QWIP, small pitch.

1. Introduction

As a general tendency in the microelectronics field, miniaturization of the products is more and more important and provides cost and system advantages. Following this general tendency, new IR staring arrays are more and more compact and offer system solutions in the different IR wavebands. In France, the HgCdTe (mercury cadmium telluride/MCT) material and process, as well as the hybridization technology, have been taken to the next even more advanced level of sophistication to offer these new staring arrays.

Thus, for mid wave (MW) applications, a 15-μm pitch TV format (640×512) HgCdTe detector, called Scorpio, is offered with a 1/4-W micro cooler with miniaturized cryogenics. This optimized dewar has been extended to TV/4 format, using the successful focal plan array which is in mass production since 2000.

Concerning long wave array, Sofradir has been offering for several years 320×256 LW detectors with a cut-off wavelength tuned between 9 and 12 μm depending on the required application. Based on that experience, two new LW HgCdTe products have been developed in 2004 and they are offered since the beginning of the year 2005. Relying on the standard HgCdTe production process with the latest improvements and on the optimized dewar family, Venus LW detector is now offered. This is a higher resolution 25-μm pitch 384×288 LW IDDCA with a 0.5-W micro cooler and with a cut-off between 9 and 10 μm for an operational temperature between 77 K and 85 K and for a spectral band pass fully satisfying the imagery requirements of compact LW FLIRs.

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This paper overviews the electro-optical and thermal performances of these three detectors and points out some reliability advantages of this new dewar design. Finally, the development trends for even higher resolution IR detector are discussed.

2. New dewar family

A new advanced dewar generation based on volume reduction and thermal performances optimization has been developed in order to lower the induced thermal constraint for the micro-cooler. The global structure of the detector has been also studied to enhance the reliability of the product.

The dewar has been optimized to offer the following improvements:

- reduced size with dimensions lower than current 320×256 detectors used in existing systems: feed through ceramics lower than 30 mm diameter and total weight without cooler of 65 grams,
- rugged mechanical design able to sustain severe mechanical environment constraints: the first vibration mode of the detector is higher than 2000 Hz in order to be compatible with most of ground mobile (GM) or airborne unmanned fighter (AUF) applications,
- enhanced thermal performances to enable the product to operate with small 1/4-W and 1/2-W micro-coolers: improvements concern the vertical thermal conductivity and the focal plane thermal mass (240 J between 20°C and 90 K) reduced by more than 20% with respect to previous generation of 1/4TV detectors,
- lower cooler electrical power consumption for system power optimization: the optimized thermal losses are lower than 200 mW (with IRFPA on) at 90 K operating temperature and 71°C ambient temperature, enabling to operate the detector with comfortable margins with a small micro-cooler at high ambient temperature. The

micro-cooler regulated power is then less than 4 W at 20°C (example of Scorpio with the small 1/4-W RM2-7i from Thalès Cryogénie/France – see Fig. 1, or with the 1/2-W K508 from RICOR/Israel),
- minimized cool down time: thanks to the detector thermal mass optimization, the cool down time has been improved by more than 40% with respect to previous generation dewar. With a RM2-7i microcooler at 90 K FPA temperature, the Scorpio cool down time is 4 min 30 s at 22°C ambient temperature and 6 min 20 s at 71°C. By increasing the detector operating temperature up to 110 K, cool down time is improved even more,
- reduction of parasitic fluxes for a more uniform and stable image over ambient temperature changes: an optimization of the cold shield efficiency has been introduced in Scorpio to reduce the parasitic fluxes due to the dewar infrared emission. When the ambient temperature changes from 21°C to 71°C, the increase in the mean output signal in front of a stable 20°C blackbody is lower than 7%, which is an excellent result demonstrating the high quality of this new optical design. This is a key parameter for improving the detector performances in term of uniformity and stability,
- enhanced detector reliability: depending on mission profile (vehicle FLIR, portable goggle FLIR...), and compared to other detectors working at a mandatory 80 K, the life time is improved by a factor 1.5 to 2.5 in duration, which is a major advantage for the global system possession cost analysis.

3. Scorpio: mid wave 640×512 15 μm pitch

In parallel of the new dewar family, the development of a HgCdTe 15 μm pitch 640×512 MW infrared detector was launched in 2003 (see Fig. 2). The aim of this detector (called Scorpio) is to offer to infrared systems a breakthrough with very high performances, less operating constraints and lower prices than the current detectors at the same format. Thus, the main objectives were to design a very high spatial and thermal resolution detector with advanced compact cryogenics to enable the users to build new compact and high resolution systems with an enhanced reliability. Furthermore, as the optical field offered by this new detector is the same that a 1/4TV format detector, and the global volume of the detector has been optimized, this detector could be an opportunity for users to upgrade their systems with a higher resolution detector keeping constant their system designs. Scorpio is available as a production product.

3.1. Global description

The Scorpio detector IRFPA has an overall area of 1×1 cm^2. The HgCdTe array is made of N-type diodes implanted in a P-type HgCdTe layer. The material cut-off is higher than 5.1 μm. Sofradir advanced ion implantation technology is used, so that IRFPA with 15 μm pitch can be produced with a high fill factor (> 80%) and a high excellent quantum efficiency of about 75%.

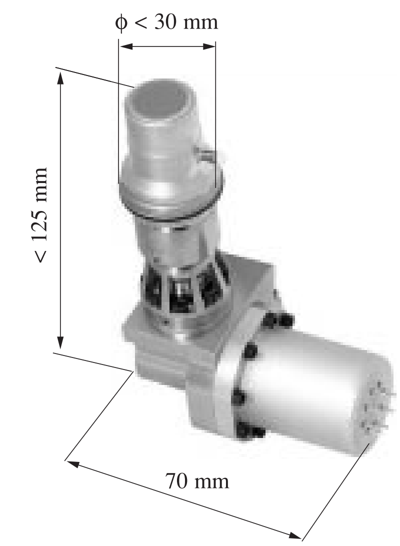

Fig. 1. Scorpio detector.

In ITR mode (integrate-then-read), the storable charge is greater than 1 pC (6.5 million electrons) and in IWR mode (integrate-while-read), the storable charge is greater than 0.7 pC (4.4 million electrons). The IRFPA power dissipation has been optimized (35 mW at 10 MHz for 120 Hz frame rate) in order to reduce the constraints on the cooler and to reduce the electrical power required to cool down the detector.

The Scorpio optical interface is comprised of a broadband MW silicon window, a germanium cold filter with a 3.7–4.8-μm spectral band pass to accurately define the detector spectral response, and a 20-mm height cold shield which is compatible with an *f*/2 optical aperture (this cold shield could be customized).

3.2. Performances

3.2.1. Spatial and thermal resolution

As far as the IR detectors spatial resolution improvement is concerned, the main parameters are the pixel modulation transfer function (MTF), the pixel pitch and the array format. These three parameters are maximized with Sofradir

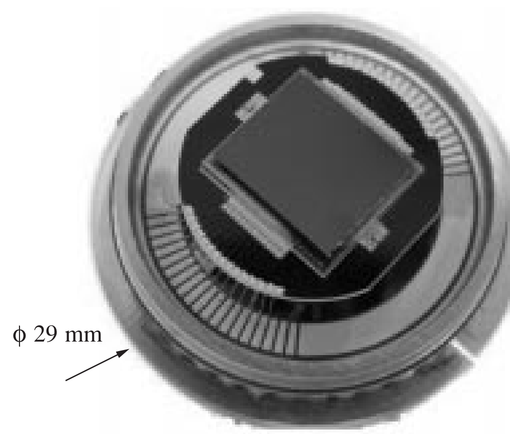

Fig. 2. 640×512 MW 15 μm pitch IRFPA integrated in Scorpio dewar.

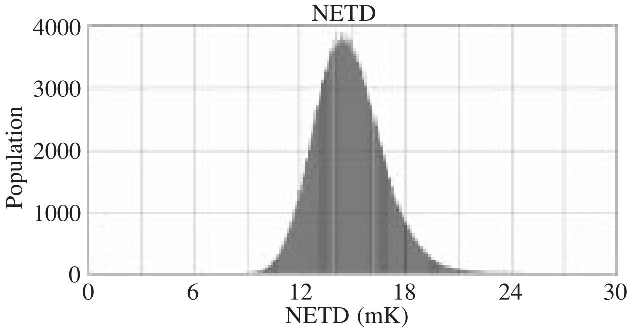

Fig. 3. Scorpio NETD measurement.

HgCdTe technology that enables to control accurately the HgCdTe diffusion length and more generally is well-adapted for low pitch detectors compared to other technologies presenting longer diffusion lengths. The crosstalk is then better than –30 dB between the illuminated pixel and the first neighbours.

For thermal resolution, two key parameters have to be considered: the temporal noise equivalent temperature difference (NETD) and the residual fixed pattern noise (RFPN).

Regarding NETD performance, Fig. 3 gives the NETD measurement of a Scorpio detector in front of a 20°C blackbody, with a 3.7–4.8 μm cold filter, an *f*/2 cold shield aperture, 4 ms integration time (for a 60% well fill) and 120 Hz frame rate at an operating temperature of 90 K. Average NETD is 15 mK and the standard deviation is 13.3%. Figure 4 presents the evolution of the NETD in a function of the operating temperature. This graph shows that the detector operating temperature can be raised up to at least 110 K while keeping constant the detector NETD performance. The evolution of the number of defects as a function of the detector operating temperature is also presented, demonstrating that the operating temperature can be raised up to at least 107 K while keeping the defects below 0.5% of the array.

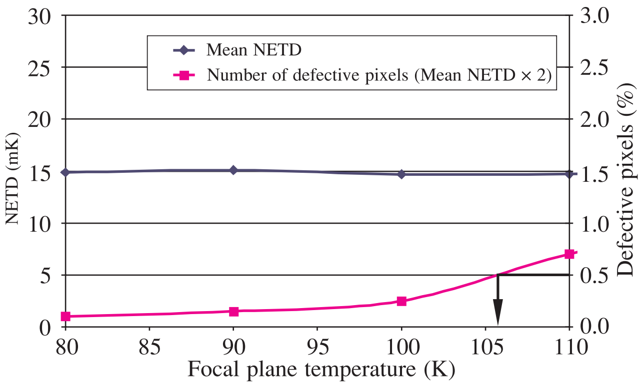

Fig. 4. NETD evolution with operating temperature.

These results confirm the quality of Sofradir HgCdTe technology and the possibility to operate the detector at a temperature higher than 100 K with an excellent sensitivity and a low number of defective pixels. As a consequence of these results, the Scorpio product will give direct benefit to the systems by making the system design and performances easier in a cost effective solution.

Figure 5 presents a defective pixels cartography of one Scorpio detector, with an operability of 99.9% (defect = NETD > 2× $NETD_{average}$ or responsivity dispersion > ±30% of average resp.) and with the largest cluster of size 10 pixels.

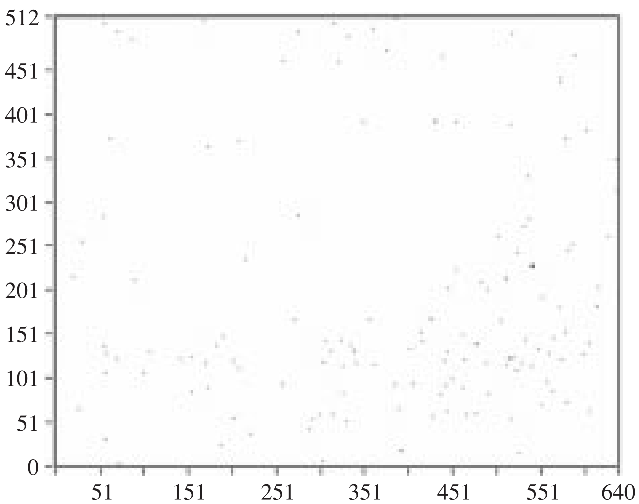

Fig. 5. Defective pixel cartography of Scorpio at 90 K.

3.2.2. Uniformity

This TV format array is one of the best products regarding the RFPN performances for MWIR products. This first-rate result is mainly due to the uniformity of the advanced Sofradir HgCdTe photovoltaic material. The typical responsivity dispersion is less than 3% (standard deviation) after field of view correction (mean value is about 2.10^{10} V/W_{peak}).

3.2.3. Non uniformity corrections: two points corrections

The RFPN computation of Fig. 6 gives the typical RFPN performances of the Scorpio having operability greater than 99.5% for a focal plane operating temperature of 90 K. The graph shows the RFPN for scene comprised between –20°C to +60°C versus the integration time. The RFPN performance is below 0.04% for this very large temperatures scene.

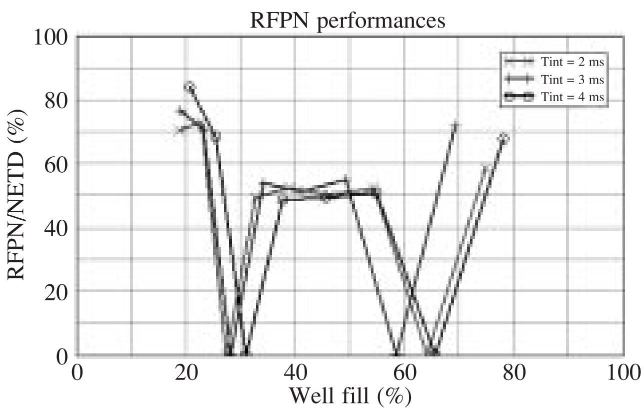

Fig. 6. FPN performances vs. integration time.

The RFPN, between the correction temperatures (about 30°C of temperature dynamic range), is less than 0.6 times the NETD (estimated in the middle of the dynamic range).

3.2.4. Focal plane temperature RFPN stability

The stability of the Scorpio RFPN performances with the focal plane operating temperature can be increased by applying a specific NUC processing. The simplest way is to include, before the application of the gain and offset correction, a correction including the focal plane temperature as the main parameter. As a consequence, it is possible to reduce the impact of the variation of the focal plane temperature on the quality of the image [1].

As shown in Fig. 7, in a standard correction, the RFPN performance after a two-point NUC is degraded by a factor of two in a range of –3/+2 K. The degradation comes from the increase in dispersion of the pixels output signal uniformity. Due to the focal plane compensation, the stability range could be increased to a FPA temperature range upper than ±5 K with an evolution of the performance less than 10%.

This capability of our detectors to be corrected is a very important asset to increase the performance of the final product regarding the stability of the focal plane operating temperature as well as to reduce the cool down time.

This focal plane temperature compensation method is a method which can be applied in real-time continuously. It just needs computing resources on a DSP coupling with an 8-bit analogue to digital conversion (ADC) on the reading of the temperature sensor installed into the product.

Based on some material improvement (MBE), the stability of RFPN versus focal plane temperature will be significantly increased.

3.3. Reliability

Thanks to the advanced dewar thermal performances optimization on one side, and on the other side to the ability of the Sofradir HgCdTe technology to operate at high focal plane temperature (90–110 K) with full performance, making it not necessary to cool down the focal plane temperatures as low as 80 K as for other type of technologies and materials, the cooler load and speed are decreased and therefore their reliability is increased. Depending on mission profile (vehicle FLIR, portable goggle FLIR...) and compared to other detectors working at a mandatory 80 K, the lifetime can be improved by a factor 1.5–2.5 in duration which is a major advantage for the global system possession cost analysis [2].

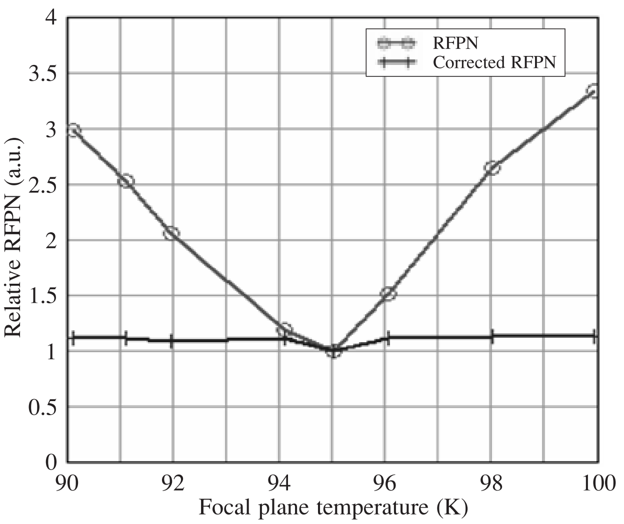

Fig. 7. RFPN versus FPA temperature without & with FPA T° compensation (corrected RFPN).

Figure 8 demonstrates the gain obtained in terms of reliability by the Scorpio type detector with respect to the previous generation of dewar for surveillance application. For this type of application the detector lifetime is mainly limited by the cryocooler lifetime and is more than 12 000 operating hours at 100 K. Of course, this limitation is all the more critical if the detector is operated at 80 K or at even lower temperature for alternative technologies. Thus, thanks to the advanced Sofradir HgCdTe technology, detector can be operated at the higher temperature to enhance the detector reliability by relaxing the cooling constraints. For example, this graph demonstrates that an operation at 100 K enables to increase the detector lifetime by more than 50% with respect to an operation at 80 K.

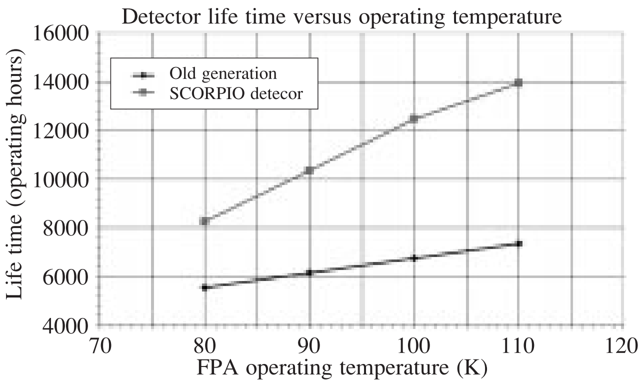

Fig. 8. Lifetime *vs*. FPA temperature for old cryogenic generation and for Scorpio detector.

Thanks to this new dewar technology, the cryogenic performances of the detector are so enhanced that the thermal constraints on the cooler are lowered and enable to use compact, low power input, and basic design coolers while increasing the detector overall reliability.

4. Mars: mid wave 320×256 30 µm pitch

The new advanced dewar generation has been extended to the existing full standard detector 320×256 30 µm pitch. This format of detector which has established Sofradir as a key player in the mid wave arrays field is now available with optimized performances, with benefits regarding cooler power consumption, mass and reliability.

4.1. Global description

Since the great success obtained with the award in 1999 for the production of the 320×256 MW detectors for current European missile program Storm Shadow, the production of this focal plan array is at mass production level.

A dewar has been developed with a 32-mm diameter feed through ceramics, implementing the improvements of the Scorpio dewar for manufacturing and cost optimizations, and adapted to the rotary micro coolers “1/4 W class” RM2 from Thales Cryogenics (France).

	3.7–4.8 μm
Storable charges	36 or 12 Me^-
Dynamic range	2.8 V
Readout noise	1500e^- (gain 36 Me^-) 800e^- (gain 12 Me^-)
Windowing	320×240, 256^2, or random
# of video outputs	4 or 1
Up to	5 MHz/output
Frame rate	up to 80 Hz full frame rate
Typical *f*/#	*f*/2
Typical NETD	< 9 mK (30% well fill- 293 K- 36 Me-)
Operability	> 99.6% typical (NETD < 2×$NETD_{average}$)
Residual fixed pattern noise	Low and stable (< NETD)
Non uniformity	5% RMS (s/mean, 300 K, un-corrected performance)
Cooler	0.25 W cryogenic rotary stirling cooler
Dimensions	Maximum diameter < 32 mm heigt: 124 mm, width: 82 mm
Weight	< 0.35 kg

Fig. 9. 30 μm pitch 320×256 MW detector characteristics.

Fig. 10. 320×256 IDDCA with 1/4-W cooler and 30-μm pitch IRFPA.

4.2. Performances

Based on this mass production of 320×256 MW focal plan array, Sofradir is today in position to exhibit very high performances in terms of thermal and spatial resolution.

Regarding spatial resolution which is a key parameter for image quality and detection range, the Sofradir technology yields diodes with a so well mastered sharp profile that pixel MTF is measured close to the theory. This know-how allows Sofradir to exhibit one of the best spatial performances with respect to the other competing 2D array technologies.

For thermal resolution, two key parameters have to be considered: the temporal noise equivalent temperature difference (NETD) and the residual fixed pattern noise (RFPN).

Regarding NETD performances, the 320×256 MW CMOS IRFPA production results (Fig. 11) highlight the high performance level achieved by HgCdTe technology for MW waveband over a very large statistical population. This very low NETD level is representative of the physical structure limitations and thus is representative of the maximum performances the system can reach. Thanks to HgCdTe characteristics, this performance remains constant up to 110 K operating temperature.

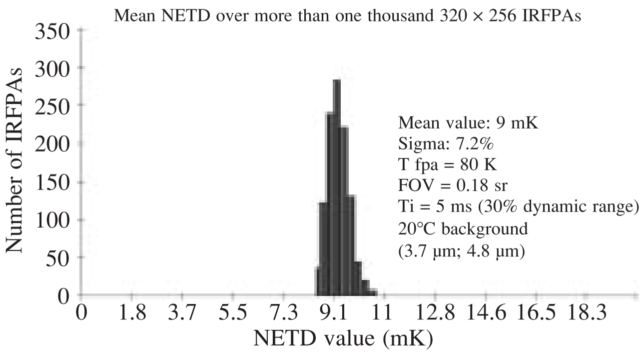

Fig. 11. Cumulated mean NETD histogram for IRFPAs.

The RFPN performances take advantage of the compactness of the new dewar family. By reducing the size of the dewar, parasitic flux and uniformity stability are improved and the stability of non-uniformity correction is better.

The thermal performances compared the previous generation of dewar are improved. The thermal mass is around 270 J between 20°C and 90°C. The dissipated power is 140 mW at 20°C (including 40 mW for the focal plan array). Power and cool down time are the following:

Maximum power		Regulated power at 90 K		Cool down time to 90 K	
20°C	71°C	20°C	71°C	20°C	71°C
< 10 W	< 14 W	5 W	< 9.5 W	5 min	< 10 min

4.3. Reliability

4.3.1. Thermal cycling

Two 320×256 MW 30 µm pitch detectors have been cycled with Joule Thomson (JT) cryocooler in a representative tactical Dewar at 90 K. Defective pixels are defined as the pixels out of 20% of the mean responsivity, or out of 30% of the mean signal, or out of 50% of the mean noise. Results show that there is no evolution regarding NETD and the number of defective pixels at 12 000 cooldown cycles.

An optimization has been performed to minimize mechanical stress. The results of these optimizations are more than 12 000 cycles for 320×256 30 µm pitch without any degradation.

4.3.2. Simulation for handheld camera

The following simulations have been performed for a 320×256 MW 30 µm pitch detector at 80 K and 110 K with a new dewar generation and a RM2-7i cryocooler.

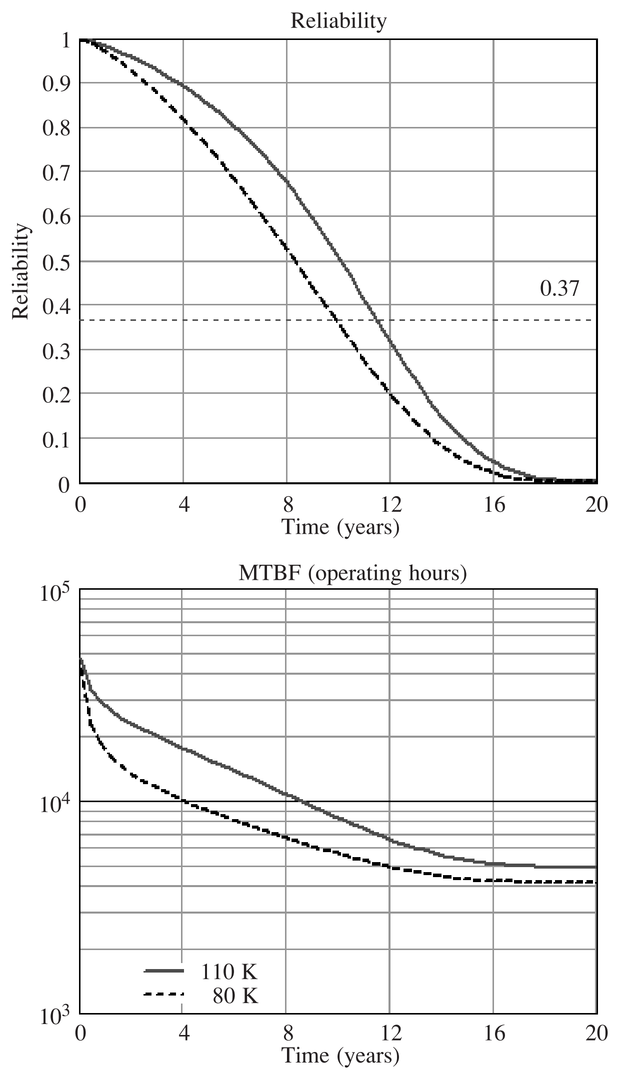

Fig. 12. Reliability and MTBF of 320×256 MW 30 µm pitch at 110 K with RM2-7i under portable camera mission profile.

Figure 12 shows that after 4 years, number of failures is divided by 2 when operating at 110 K instead of 80 K. After 8 years, number of failures is nearly 30% for 110 K applications instead of 50% for 80 K applications. So, the gain in reliability is very important.

This figure also shows that MTBF is nearly 4 000 operating hours for 80 K application and nearly 5 000 operating hours for 110 K applications. However, the operating temperature has a strong impact if life duration is defined with a MTBF criterion. For example, if we consider that the detector is cost-effective till MTBF > 10 000 operating hours, life duration is 4 years for 80 K applications and 8.5 years for 110 K applications.

The reliability at 80 K is limited by the cryocooler instead of 110 K application where the global wear out of the IDDCA starts to limit reliability. For applications with the operating temperatures lower than 80 K, the cryocooler limitation is more important and 1/4-W cryocooler cannot be used anymore. Regarding life cycle costs, a more powerful cryocooler is required which means a higher acquisition cost to reach the same reliability level. It also means larger size, higher power consumption (lower battery autonomy), and higher power dissipation in the camera (higher ambient temperature in the camera for all equipment).

5. Venus: LW 384×288 25 µm pitch

For answering new system needs, requiring fast frame rate HgCdTe long wave staring array with the European TV/4 format, a 25 µm pitch 384×288 ROIC was developed at Sofradir in 2004, as well as a miniaturized dewar family based on the new concepts implemented in the MW 640×512 15 µm pitch Scorpio detector, while being still compatible with previous 320×256 30 µm pitch IRFPAs 3.

5.1. Global description

A dewar has been developed with a 32 mm diameter feed through ceramics with 41 pins, implementing the latest improvements for manufacturing and cost optimization, and adapted to the rotary microcoolers "1/2 W class" K508 from Ricor (Israel), and "1/4 W class" RM2 and 0.7 W class" RM4 from Thales (France).

With the K508 cooler, the total IDDCA weight is less than 0.55 kg (1.21 lb) and the dimensions are 143 mm height and 71 mm width (Fig. 13). With the RM4 cooler, the total IDDCA weight is less than 0.65 kg (1.43 lb) and the dimensions are about 130 mm height and 74 mm width.

The optical interface is made of the dewar window, the cold filter and the cold shield. The 1.6 mm germanium window ensures a very high parallelism and planarity, and has a broadband antireflection coating optimized for LW transmission. A cold filter is implemented on the cold shield to define the spectral response. The cold shield has a 20-mm height (above the IRFPA), with a typical aperture of about 10.5 mm for *f*/2 applications. Smaller aperture between *f*/2 and *f*/4 are customizable.

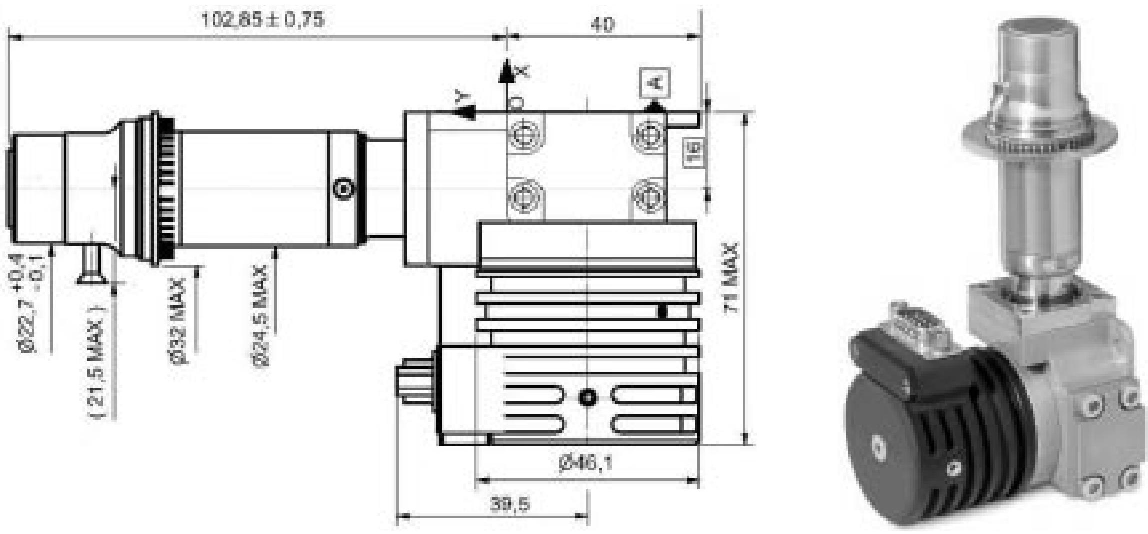

Fig. 13. Venus-LW detector: 384×288 LW HgCdTe IDDCA with 0.5 W K508.

The maximum charge handling capacity is 34 million of electrons (gain 1, 100% of well fill).

5.2. Performances

The spectral response of this 384×288 LW IDDCA is defined by the cold filter: this filter can be offered as a high pass filter, with the HgCdTe material ensuring the cut-off for maximizing the detection range, or as a band-pass filter (7.7–9.0 µm for instance) to optimize the cut-off sharpness and global uniformity of the spatial response.

Figure 14 illustrates a spectral response with a cut-on at 7.7 µm performed by a high pass cold filter, and the cut-off performed by the HgCdTe material at 9.57 µm at 50%, and 80 K.

The following data give an example of one array representative of deliverable detectors. The IRFPA is measured at *f*/2.24, at 77 K, in front of a 300 K blackbody, with a high pass cold filter providing a spectral response given in Fig. 14.

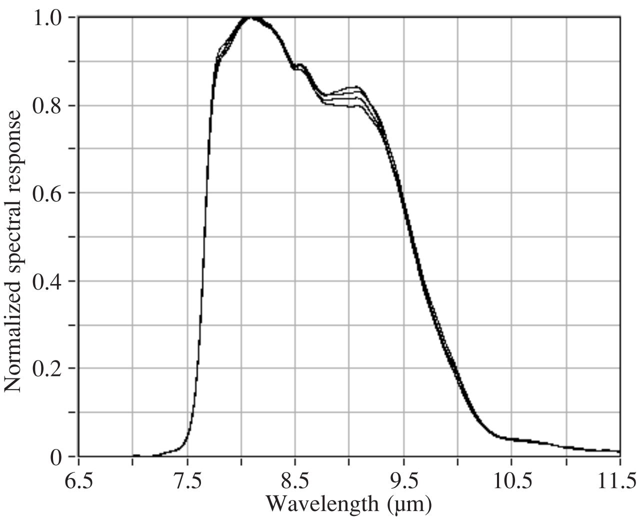

Fig. 14. 9.5 µm 384×288 HgCdTe detector, spectral response at 80 K with high pass filter.

The integration time is chosen at 600 µs in order to be at 50% well fill of GAIN 1 (34Me-). Set in 4 output default mode, the full array working in integration then read mode is therefore output at a high frame rate of 160 Hz with 5 MHz master clock or 300 Hz with 10 MHz master clock.

The mean DC level is 1.5 V (mid dynamic) and the dispersion σ/mean is 5.8% without FOV correction. There are 76 defects (0.07%) at ±40% spread from DC mean, and 89 defects (0.08%) at ±30% spread from DC mean.

The mean 20–35°C responsivity is 26.4 mV/K (= 8.25 10^8 V/W), and the dispersion σ/mean is 4.8% without FOV correction. There are 63 defects (0.06%) at ±40% spread from mean and 70 defects (0.06%) at ±30% spread from mean.

The mean NETD at 50% well fill is 18 mK and the dispersion σ/mean is 12% with FOV correction (see Fig. 15). There are 249 defects (0.23%) at 3×$NETD_{mean}$ (see Fig. 16).

This IDDCA has been developed for military FLIRs conditions and it is hardened against low resonance frequencies. It sustains classical military environments with random vibrations spectrum up to 2000 Hz, and with ambient temperatures up to 71°C (IDDCA skin temperature).

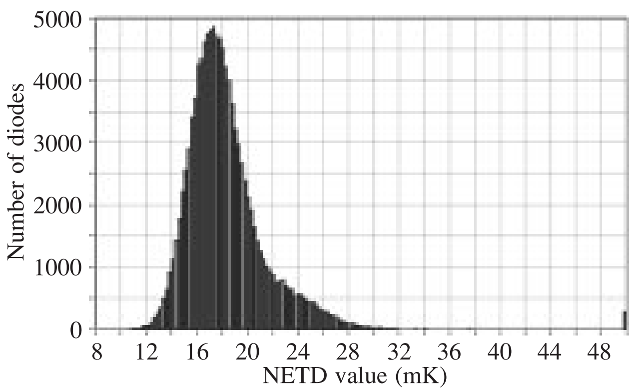

Fig. 15. NETD histogram (18 mK mean, 12% σ/mean).

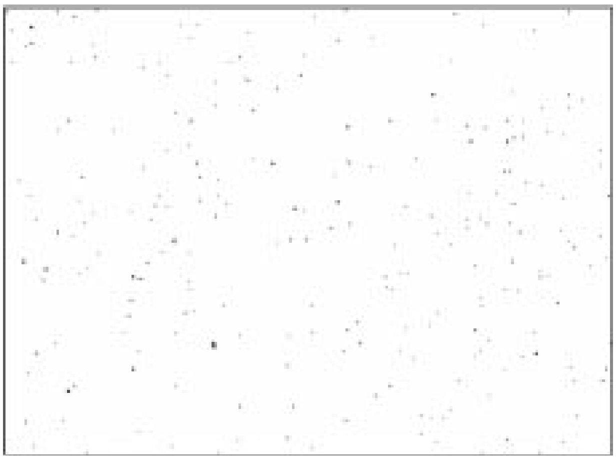

Fig. 16. 249 NETD defects (0.23%) at 3×mean.

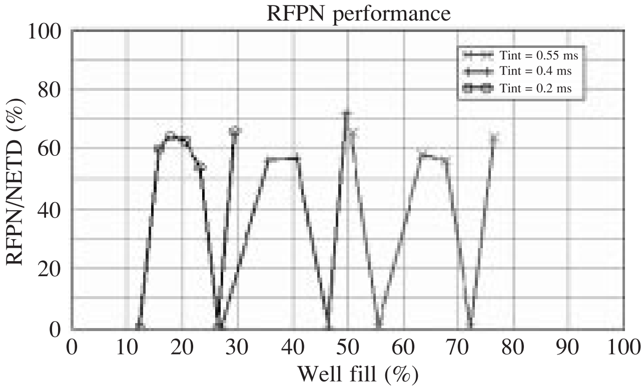

Fig. 17. RFPN performances vs. integration time.

The 9.5 µm HgCdTe cutoff wavelength enables to operate the IRFPA in a temperature range from 77 K to 85 K while still presenting a high level of performance.

An improved HYB18 driving electronics is implemented in the K508 cooler, to reduce the drift of the operational temperature set point below 1.1 K when ambient temperature varies from +71°C to –40°C, leading to stable performance for a long wave IRFPA (responsivity and noise have been measured constant over this –46°C to +71°C range). This is a drastic improvement compared to previous K508 HYB10 driving electronics that could present a drift larger than +4 K between +20°C and –40°C and that could lead to electro-optical performance degradation in cold ambient temperatures.

The following thermal performances have been measured on two detectors set around 77 K operating temperature, with the K508 cooler equipped with the HYB18 driving electronics.

The evolution of the cool down time (CDT) from ambient temperature to 77 K, IRFPA being turned on at 125 K, is around 3 min 30 s at –40°C, around 5 min at 20°C, and is less than 7 min at 71°C.

The evolution of the power consumption during CDT (P_{max}) and during regulation around 77 K (P_{reg}) are the following: P_{max} is < 9 WDC at –40°C, < 13 W_{DC} at 20°C and < 14 W_{DC} at 71°C; and P_{reg} is < 4 W_{DC} at –40°C, < 7 W_{DC} at 20°C and < 9.5 W_{DC} at 71°C.

The parasitical flux has been optimized and the Venus-LW product shows less than 2.8% of output signal increase between 20°C to 71°C including the unavoidable variation of the focal plane temperature array due to the integrated cooled stability performance.

The RFPN computation illustrated in Fig. 17 gives the typical RFPN performances of the Venus-LW (with operability greater than 99.5% for a focal plane operating temperature of 81 K) and shows the RFPN for scene comprised between 20°C to 60°C depending on the integration time. The performance in RFPN is below 65% of the measured NETD for this large temperatures scene.

The RFPN, between the temperatures of correction (20, 40, and 60°C, respectively, of temperature dynamic range for integration times of 0.55, 0.4, and 0.2 ms), is less than 0.65 times the measured NETD.

The RFPN after a new cooling down is just degraded by a factor two. A one point correction is enough to reduce the RFPN to a value less than the measured NETD. The quality of the image obtained is presented in Fig. 18.

6. Higher resolution for IR detector developments

Scorpio, Mars, and Venus present consistent solutions for compact mid-wave and long-wave applications. However, increase in spatial resolution with small pixel pitch and large array format is anticipated for preparing the future military and industrial needs.

Fig. 18. Images with the Venus-LW camera, focal plane temperature 77 K, simple 2-point NUC.

6.1. Large MW format: Saturne: 1280×1024 15 µm pitch, MCT

For answering these needs, Sofradir is working with CEA-LETI/LIR in the frame of DEFIR (design of excellence for the future of infrared), on the third generation R&D mainly based on HgCdTe (MCT) material growth by molecular beam epitaxy (MBE) [5].

Based on MCT grown by MBE, large wafers (4 inches and more) are available on germanium in France and on silicon in the USA. MBE process on alternative materials like germanium, are in position to replace CZT homo-substrates and to compete with other material candidates. This enables very larger wafer size (4" and more) with a well-mastered thickness of the sensitive thin film deposition leading to very low cost 2D MCT arrays.

The first demonstration of Sofradir is an HgCdTe 1280×1024 MW array with 15 µm pitch. It is made of a silicon readout circuit (ROIC) hybridized to an MCT MW array. The new MCT material based on MBE on a 4-inch germanium substrate will be used to produce this very large array in order to obtain a very high uniformity and an affordable IRFPA. The MCT array is made of N-type diodes implanted in a P-type MCT layer. The material cut-off is higher than 5.1 µm and the fill factor is higher than 80% with a high quantum efficiency of about 80%.

This very high resolution IRFPA will require a high performance cold shield system. Thus, a 30-mm height cold shield adapted to small f-number down to 1 is offered.

Thermal mass and thermal heat load have been minimized and the dewar is used with a one Watt linear Stirling engine. Figure 19 presents the dewar design.

Fig. 19. Dewar design for the 1280×104 MWIR.

Regarding the sensitivity, the ROIC floor noise (about 150 µV) and the maximum storable charge in the ROIC are compatible with a NETD below 20 mK at mid-dynamic range.

As a conclusion, this 1280×1024 MW 15 µm pixel pitch detector is designed to be affordable and to answer very high resolution system requirements. This development is in progress and the units will be available at the end of 2005.

6.2. Large LW format: SIRIUS, a 640×512 20 µm pitch QWIP

Since 1997, Sofradir and Thales Research Technology (TRT) worked in cooperation to develop quantum well infrared photodetectors (QWIP) implemented by Sofradir on the same production lines than HgCdTe, and offering a LW staring array alternative to HgCdTe technology for large LW array formats.

Manufactured at TRT by molecular beam epitaxy (MBE) on a 3-inch GaAs wafer (Fig. 20), this QWIP detector is made of a regular GaAs/AlGaAs structure, similar to the one already used for Thales's Catherine-QW FLIR 7. The QWIP structure is optimized as a compromise between high FPA temperature, acceptable NETD, and manufacturing cost. Of course, a customized structure could be also offered for maximized E&O performance (NETD < 15 mK), if the system is accepting an operating temperature below 70 K with an associated large power split Stirling cooling engine.

A new dewar was derived from the Sofradir 640×512 20 µm pitch mid-wave HgCdTe IDDCA and was adapted to the "0.75 W class" K548 rotary microcooler from Ricor (Israel) with a large cold finger, for an operating temperature between 70 K and 75 K. The 9-mm diameter "large"

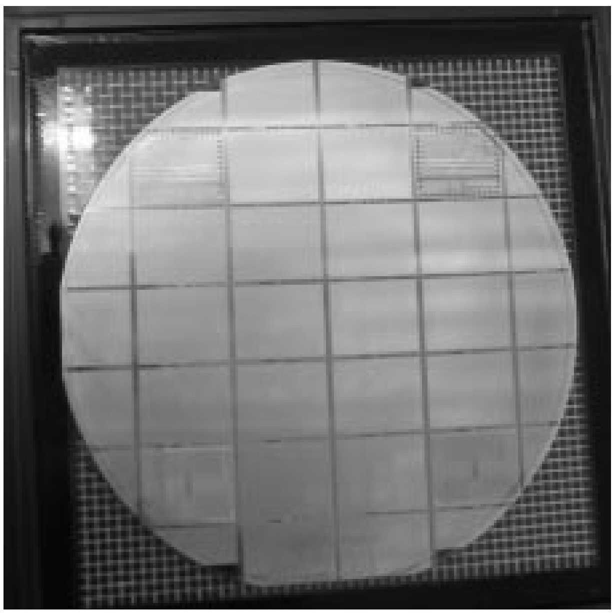

Fig. 20. 3-inch GaAs wafer with 16 640×512 QWIP arrays.

cold finger of the K548 gives the IDDCA the sufficient cryogenic power for > 70 K operating temperature under any military ambient temperature conditions (up to 71°C).

The operability will be above 99.9% (NETD > $2\times NETD_{average}$), as already demonstrated on previous manufactured QWIP detectors. This detector is available as a production product.

7. Conclusions

By taking advantage of the single production line for short wave, mid wave, and long wave HgCdTe detectors, Sofradir is able to offer detectors to answer most needs of the IR market.

Sofradir proposes Scorpio for a full TV format coupled with a reduced cost and size as well as an increase in IDDCA (integrated detector Dewar and cooler assembly) reliability. Scorpio operates in the 3–5 µm waveband, comes with the market's smallest cryocooler and has four times more pixels than standard 320×256 mid-wave infrared detectors. This enables higher sensitivity, low input power consumption and better image quality at greater distances. This high resolution detector will bring substantial savings to the overall system by taking its mercury cadmium telluride (MCT/HgCdTe) material and process as well as its hybridization technology to the next even more advanced level of sophistication.

The LW FLIRs making use of TV/4 format detectors can now choose between the 320×256 30 µm pitch detector and the new Venus-LW 384×288 25 µm pitch detector. This Venus detector offers higher resolution in a smaller ϕ 32 mm dewar and exhibits very high typical performance representative of the standard Sofradir process (18 mK NETD, < 0.3% defects, < 6% standard deviation on uncorrected DC level) with full array size at frame rate up to 300 Hz.

In parallel, third generation studies are carried on up DEFIR, relying on MCT worked out by molecular beam epitaxy. Last results for large format 1280×1024 are very promising.

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References

1. P. Fillon, "Cooled IR detector calibration analysis and optimization", *Proc. SPIE* **5784**, 343–354 (2005).
2. X. Breniere and J.M. Cauquil, "Reliability optimization for IR detectors with compact cryocoolers", *Proc. SPIE* **5783**, 187–198 (2005).
3. A. Manissadjian, "Long wave HgCdTe staring arrays at Sofradir: from 9 µm to 13+µm cut-offs for high performance application", *Proc. SPIE* **5783**, 231–242 (2005).
4. A. Manissadjian, E. Brochier, and P. Tribolet "New compact staring detectors for MW and LW applications", *Proc. SPIE* **5612**, 21–31 (2004).
5. P Tribolet and G. Destefanis, "Third generation and multicolour IRFPA developments: a unique approach based on DEFIR", *Proc. SPIE* **5783**, 350–356 (2005).
6. P. Ballet, P. Castelein, J. Baylet, E. Laffosse, M. Fendler, F. Pottier, S. Gout, C. Vergnaud, S. Ballerand, O. Gravrand, J.C. Deplanche, S. Martin, J.P. Zanatta, J.P. Chamonal, A. Million, and G. Destefanis "Demonstration of a 25-µm pitch TV/4 dual-band HgCdTe infrared focal plane array with spatial coherence", *Proc. SPIE* **5957**, 595703 (2005).
7. A. Manissadjian, "New QWIP products at Sofradir", *OPTRO* 2002 -Paris, January 14–16, 2002.

