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Latest Developments of Cooled Infrared Detectors at Sofradir, France

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ABSTRACT

This short article describes the recent developments of cooled infrared products at Sofradir. These developments are driven by the future systems needs like the increase in resolution and detection range, the reduction of the detector size and consequently of the pixel pitch and the reduction of the power consumption. To answer to these needs, Sofradir develops in collaboration with the French infrared laboratory (CEA-LETI) new products based on Mercury Cadmium Telluride technology: Scorpio LW 640 x 512/15 µm pitch, sensitive in the long wavelength, Jupiter MW 1280 x 1024/15 µm pitch sensitive in mid wavelength, HOT detectors operating at 150 K and the 10 µm pitch detectors.

Keywords: Sofradir, infrared, sensor, high operating temperature infrared, long-wave-infrared, mid-wave-infrared

1. INTRODUCTION

Infrared cooled detectors based on Mercury Cadmium Telluride (MCT) technology have been developed in France for more than 25 years by Sofradir and CEA-LETI in the frame a joint laboratory. The MCT material was chosen in the past for its potential regarding the needs of future systems and its flexibility. Indeed, this material has the capability to detect the radiation in a large spectral band from UV to far infrared with very good quantum efficiency. Thanks to its adjustable cut-off wavelength, playing on the composition of *Hg, Cd,* and *Te,* infrared detectors are optimized for each wavelength.

The future systems needs to confirm the choice of the MCT material. The trends of the cooled infrared market are oriented towards the miniaturization and the new functionalities without any compromise on the performances.

The miniaturization is known under the word, small weight and power (SWaP). The aim is to reduce the size, the weight and the power consumption of the infrared detectors. This miniaturization is especially important for the compact systems or portable systems in order to make the equipment of the soldier lighter, playing mainly on the weight of the batteries. To answer to this demand, Sofradir and CEA-LETI are developing small pixel pitches, down to 10 µm and high operating temperature (HOT) detectors.

On the other hand, embedded systems on vehicle or airplane have not the same needs. They need first high performances and new functionalities like large format, high resolution, high sensibility and high speed, dual colors or laser active imaging using avalanche photodiode technology.

This paper describes the infrared technology used and gives some examples of developments of MCT infrared detectors at Sofradir regarding:

- HOT detector operating at 150 K sensitive in the mid wavelength from 3 µm to 5 µm (MWIR).
- Small pixel pitch of 10 µm.
- Scorpio LW : 640 x 512 / 15 µm pixel pitch sensitive in the long wavelength from 8 to 10 µm (LWIR).
- Jupiter MW : 1280 x 1024 / 15 µm pixel pitch sensitive in the mid wavelength from 3 to 5 µm.

2. TECHNOLOGIES

Sofradir infrared detector is a hybrid of a matrix of photodiodes made of MCT material onto a silicon readout circuit. The matrix of photodiodes converts the photons in small electrical signals which are amplified and multiplexed by the readout circuit. The interconnection between the detection module and the readout circuit uses indium bumps. Figure 1 shows the structure of a hybrid.

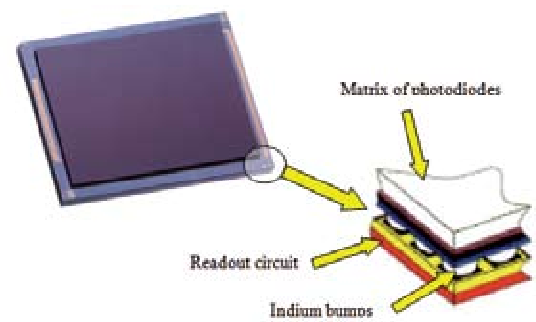

Figure 1. Matrix of photodiodes hybridized onto a silicon readout circuit.

Due to the intrinsic dark current of photodiode, this detector can operate only at cryogenic temperature. The hybrid is packaged into a vacuum dewar and cooled by stirling cycle cryocooler as shown in Fig. 2.

Among the technologies entering into a cooled infrared detector, the key one is the matrix of the photodiodes. The

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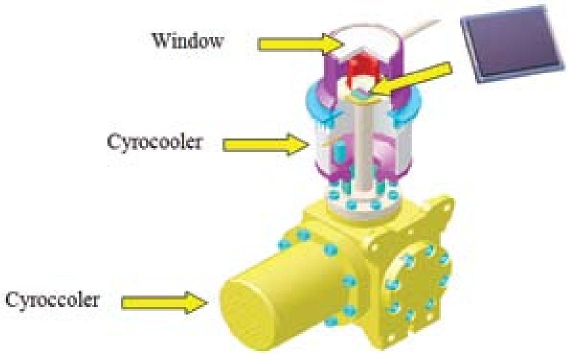

Figure 2. View of the dewar and the cryoccoler.

photodiodes are implanted into an epitaxy layer of MCT processed onto Cadmium Zinc Tellurium (CZT) substrate. These substrates are home processed using the vertical Bridgman growth technique. The performance of the detectors depends on the quality of the substrate and the epitaxy layer.

It is essential to have a very high quality substrate to get a good lattice matched with the epitaxy layer with a minimum of defects. The challenge is to get a good quality material in large substrates. As for the microelectronic industries, the trends are to increase the wafer size in order to reduce the detector unit cost and to increase the manufacturing capabilities.

The epitaxy process is another key parameter for the quality of detectors. The main parameters of the detector like the cut-off wavelength, the uniformity, the sensitivity and number of defective pixels depend strongly on this process. Two types of epitaxy process are used: Liquid phase epitaxy (LPE) or Molecular beam epitaxy (MBE). CZT or alternative substrate can be used for MBE process. It is preferable to use CZT substrates in order to have a lattice matched as perfect as possible, especially for top quality detectors or HOT detectors. Figure 3 gives samples of ingots and substrates with epitaxy layer.

3. HOT INFRARED DETECTORS

Why high operating temperature (HOT) detectors? A few years ago the operating temperature was limited to values less than 90 K for MWIR detectors. This operating temperature is mainly limited by the dark current which is an increasing function of the temperature. Usually the operating temperature is set in order to reduce the dark current to a value lower than the useful current (typically from 2 to 10 times lower). Relaxing the operating temperature is a good way to reduce the size, the weight and the power consumption of infrared detectors. For instance, for a given detector, relaxing the operating temperature from 80 K to 150 K allows to divide by three the power consumption of the cryocooler, with significant wins on the weight of the batteries or on the autonomy. Or using the same cryocooler than the one used at 80 K, to increase the reliability of the detector thanks to the fact that the cryocooler is oversized. See Fig. 4 and reference[1] for more details.

So the increase of the operating temperature needs infrared technology with low dark current. Thanks to a new

Figure 3. CZT ingots, substrates and MCT epitaxy layer process.

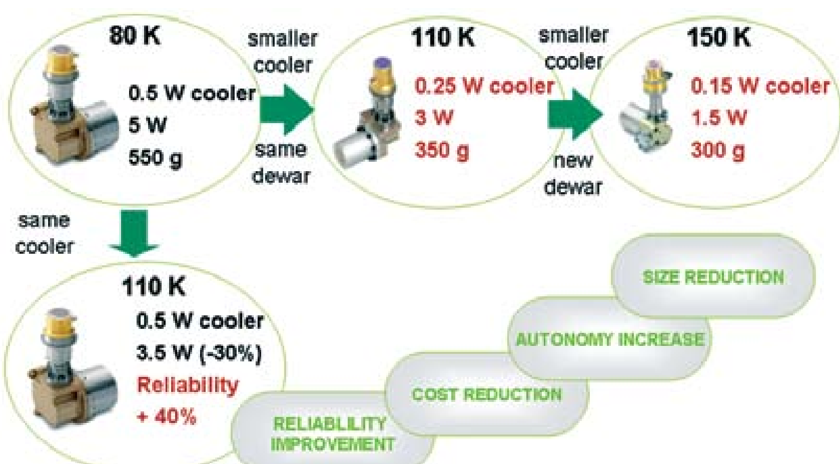

Figure 4. Advantage of the increase of operating temperature on the cooling system of the infrared detector.

low dark current MCT technology using p-on-n photodiodes, the operating temperature can be pushed back to 150 K without any decrease of the sensitivity. The Fig. 5 shows the noise equivalent temperature difference (NETD) of a 640 x 512 / 15 µm pitch detector versus the operating temperature. The blue curve is the simulation and the blue dots are the measurements. The NETD is still lower than 15 mK up to 170 K. The dark current starts to have an effect from 150 K as shown by the decrease of the integration time in order to maintain the well fill at 50 %. Measurements conditions are: spectral band from 3.7 µm to 4.8 µm, optical aperture f/2, 50 % well fill and frame rate > 50Hz.

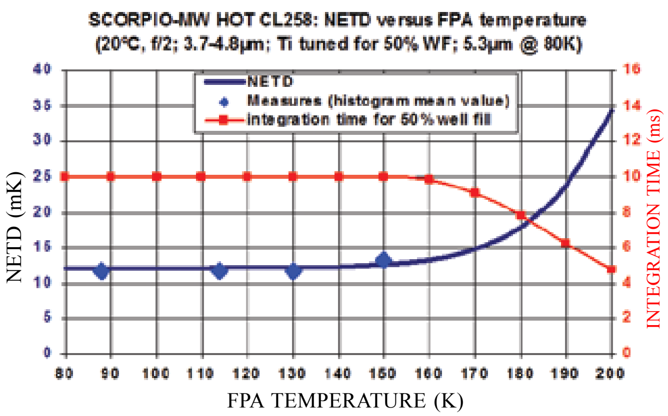

Figure 5. Sensibility (NETD) and integration times *vs* operating temperature.

The operating temperature is not only limited by the dark current but also by the defective pixels. The second challenge is to increase the operating temperature without any effect on the number of defective pixels. This is characteristic of the quality of the technology used and especially the quality of the detecting material. The measurements show that the operability of the p-on-n MCT technology is still good with the increasing temperature up to 150 K at least. Figure 6 illustrates the very good performance measured. The operability (defined as pixel NETD >2 x mean NETD) is extremely good, higher than 99.8 % between 88 K and 130 K, and still 99.4 % at 150 K.

These results are obtained using LPE process on lattice matched substrates of CZT. This process is better than other process as MOVPE or MBE on AsGa substrates to master the number of defective pixels with the increasing of the temperature. Indeed, with MOVPE or MBE process, the operability is about 98 % at 150K compared to 99.4 % with LPE process.

The production of infrared detector operating at high temperature (about 150 K) is expected in a near future for new smaller and lighter portable systems.

4. SMALL PIXEL PITCH

The trend is in the reduction of the pixel pitches for several reasons. First reason is to miniaturize the infrared detectors without any decrease in the number of pixels. Thanks to the small pixel pitches, for a given number of pixels, detectors become more and more compact, need less power and are cheaper. The second reason is to increase the resolution of the systems and consequently the detection range.

Today, 15 µm pixel pitch is a standard for the MWIR detectors. One can find in the Sofradir catalog a complete range of detectors with pixel pitch of 15 µm: Epsilon (384 x 288), Scorpio (640 x 512) and Jupiter (1280 x 1014).

The next step is the pixel pitch in the range of 12/10 µm. The reduction of pixel pitch to 10 µm is a challenge because it requires some technological breakthroughs. The simulations show that a detector with a 10 µm pitch has a detection range 20 % higher than a detector of same surface with a pitch of 15 µm and an optical aperture of f/4. As shown in Fig. 7. These simulations are made using the TRM4 program from Fraunhofer IOSB.

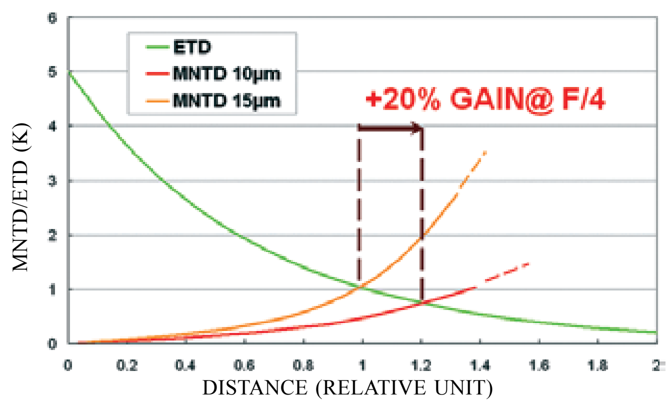

Figure 7. Gain in detection range with 10 µm pitch.

The reduction to 10 µm needs some technological breakthroughs at level of the pixel: first the implanted diode needs to be well mastered to avoid cross-talk, second the hybridization process shall be capable to maintain a good yield of connection and a good reliability, and third the current injection in the readout circuit shall be mastered. Indeed, with low optical aperture, the current coming from the diode is so low that problem of coupling with the readout circuit may occur.

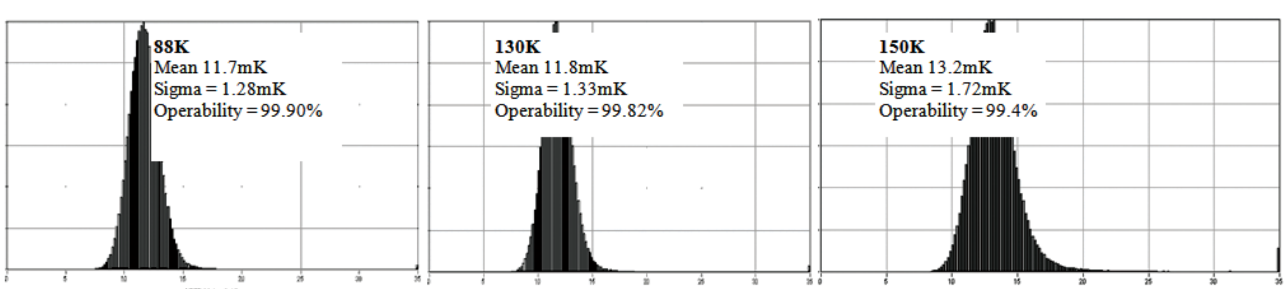

Figure 6. NETD histograms stability of the p/n MW MCT in HOT conditions.

The demonstration of the capability of the MCT technology to achieve pixel pitch of 10 µm was performed recently. The demonstrator is a 320 x 256 MWIR detector using standard planar technology. As shown in Fig. 8.

Figure 8. MWIR demonstration with 10µm pixel pitch.

5. SCORPIO LW

The detection in the long wavelength (from 8 µm to 10 µm) has some advantages compared the detection in the mid wavelength (from 3 µm to 5 µm). Usually ground applications prefer the LWIR detectors because they are less sensitive than MWIR detectors to the blooming effects and to aerosol or smoke, due to atmosphere transmission. Sofradir has developed Scorpio LW, a compact / high resolution detector with a pixel pitch of 15 µm well adapted to vehicle applications (gunner and/or commander) or for Remote Weapon Station. This detector of 640 x 512 pixels is made using the MCT p-on-n technology and is sensitive from 7.7 µm to 9.5 µm (Fig. 9).

The main characteristic of Scorpio LW is given in the following Table 1.

Figure 9. Scorpio LW with K508 cryocooler from Ricor.

6. JUPITER MW

Among the latest introduced detectors, the 15 µm pixel pitch Jupiter MW (1280 × 1024/15 µm pixel pitch) answers to very high resolution needs and high performance applications: FLIR, IRST, reconnaissance, surveillance and airborne cameras. Jupiter operates up to 110 K with a NEDT of 18 mK. It presents a very good operability (above 99.8 %) and an excellent uniformity in cut-off wavelength. Figure 10 shows a long distance IR observation taken with Jupiter.

Table 1. Main characteristic of Scorpio LW

Parameter	Typical value
Format	640 x 512
Pixel pitch	15 µm
Spectral response	7.7 to 9.5 µm
Operating temperature	< 90 K
Storable charges	13 Me-
Output dynamic	2.8V (analog outputs)
Number of outputs	4 @ 20 Mpixel/s each
Maximum frame rate	< 210 Hz
Optical aperture	f/2 to f/4
NETD	< 25 mK

Figure 10. Long distance image taken with this FPA.

Jupiter has to deal with challenging specifications regarding dewar compactness, low power consumption and reliability. It is available in a new versatile compact dewar that is vacuum-maintenance-free over typical 18 years mission profiles, and that can be integrated with the different available crycoolers: K548 for light solution (less than 0.7 kg), K549 or LSF9548 for split cooler and/or higher reliability solution.

The main characteristic of Jupiter MW is given in the following Table 2.

Table 2. Main characteristic of Jupiter MW

Parameter	Typical value
Format	1280 x 1024
Pixel pitch	15 µm
Spectral response	3.7 µm to 4.8 µm
Operating temperature	< 110 K
Storable charges	1.3 Me- and 4.3 Me- (2 gains)
Output dynamic	2.8V (analog outputs)
Number of outputs	8 @ 20 Mpixel/s each
Maximum frame rate	< 120 Hz
NETD	< 18 mK

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CONTRIBUTOR

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