T2SL TECHNOLOGY DEVELOPMENTS IN MWIR BAND OPERATING AT A HIGH TEMPERATURE

N. Péré-Laperne(1), A. Brunner(1), G. Dagher(1), R. Toscano(1), A. Blay(1), C. Zoller Martinet(1), J. Coussement(1), A. Evirgen(2), J.L. Reverchon(2), G. Gregoire(2), C. Cervera(3), O. Gravrand(3)

(1) LYNRED, Actipole - CS 10021, 364 route de Valence, 38113 Veurey-Voroize, France
(2) III-V Lab, Campus de Polytechnique, 1 avenue Augustin Fresnel, 91767 Palaiseau, France
(3) CEA-LETI, MINATEC Campus, 17 Rue des Martyrs, 38054 Grenoble Cedex 9, France

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ABSTRACT:

LYNRED is leading the development of infrared detectors for high performances applications. Two trends are identified in the infrared range, the increase of the operating temperature and the pixel pitch reduction. For 15 years, the III-V technologies present an increasing interest to address both challenges. At LYNRED, these technologies allow to address Short Wave InfraRed (SWIR) and Mid-Wave InfraRed (MWIR) for ground applications. The latter is addressed thanks to bulk InAsSb material as well as the type-II superlattices (T2SL) depending on the wavelength range. Based on LYNRED's knowhow, T2SL material is under development to offer a complete product line in the full MWIR range, from 3.5 up to 5.1 µm. Many challenges have to be addressed for the future focal plane arrays (FPAs). Electrical and optical crosstalks as well as image quality and stability, are one of the prime concern for detectors with pixel pitch down to 7.5µm. In order to reach an industrial production level of infrared FPAs, technological developments are required at each steps: the epitaxy, the detector array process, flip chip and back end processing. Another key element is the Read Out Integrated Circuit (ROIC) design in-house to fulfil our customer needs.

We review the latest developments at LYNRED on T2SL technology, in terms of operability, residual fixed pattern noise (RFPN) and Modulation Transfer Function (MTF) optimizations.

1. INTRODUCTION

The first photon detector material was based on a III-V material, *InSb*. [1] Then, II-VI material and more precisely *HgCdTe*, has emerged as an alternative allowing to cover the entire infrared (IR) spectrum from 1µm up to 17µm. The latter is the legacy material at LYNRED as it is developed, industrialized and in production for nearly 40 years. Ten years ago, LYNRED benefited from a transfer of three different technologies based on different III-V materials and integrated some new products in its portfolio. These IR focal plane arrays were based on *InSb* [2], *InGaAs* [3] and *GaAs/AlGaAs* Quantum Well Infrared Photodetector (QWIP).

In parallel over the last decade, significant efforts have been made to develop high operating temperature detectors in the MWIR band. These developments aim at offering new products to address the SWaP (Size, Weight, and Power) criterion. Different product segments drive the growing demand for compact and low consumption infrared cooled detectors. Hand Held Thermal Imagers, UAV, small gimbals are some of them.[4] Both II-VI [5] and III-V [6] materials developed solutions to address it.

Focusing on III-V materials, two different solutions can be used, the bulk *InAsSb* with a 4.2µm cutoff wavelength and Type II Superlattice (T2SL) to address the full MWIR band both at a high operating temperature (HOT). To be more specific, the performances of T2SL are improving fast moving from *Gallium* contain superlattice [7] to *Ga* free superlattices. [8] The latter allowed introducing different developments with a 15µm pitch [9] and a 5µm pitch [10] both operating in a 120-130K range.

In this paper, two different focal plane arrays are presented addressing the full MWIR band using a III-V active layer. The first is a VGA 15µm pitch (Section 2) and the second is a SXGA 7.5µm (Section 3). These two are operating at 130K.

For these detectors, a full set of characterizations is shared including residual fixed pattern noise (RFPN) and the Modulation Transfer Function (MTF).

2. FULL MID-WAVE INFRARED VGA 15µM PITCH

2.1. Detector technological definition

This Focal Plane Array (FPA) has been developed and it is in industrialization now. The prototypes are available for the customer evaluation. It is addressing the full MWIR band thanks to an absorbing layer made out of T2SL. The characteristics of the T2SL are defined to reach a 5.1 +/- 0.1µm cutoff wavelength. This FPA is operating at a temperature of 130K and is characterized with a F/5.5 aperture. The cold filter is a [3.7, 4.8]µm band pass filter.

2.2. ReadOut Integrated Circuit

The VGA 15µm pitch Read Out Integrated Circuit (ROIC) has been designed by LYNRED. The ROIC is manufactured by a Silicon CMOS foundry. As described in Table 1, the ROIC can reach two different gains allowing many use cases of application. A very good linearity has been demonstrated in the entire well fill range. The power consumption in full frame at 130K is low, close to 60mW and a well suited frame rate of 60Hz for imagery in full format.

Table 1: VGA 15µm pitch ReadOut Integrated Circuit characteristics

	15µm pixel pitch ROIC
Format	640x512 (VGA)
Integration modes	Snapshot - ITR/IWR
Storable charges	2.1Me-
Linearity	+/- 0.5%
Consumption	60mW (full frame & 130K)
Frame Rate	60Hz (full format)
Functions	Windowing, Line/row inversion,

Post processing of the ROIC wafers is performed by LYNRED in order to allow the flip chip bonding using indium bumps. This kind of flip chip is the best suited for a high yield and a good reliability at a cryogenic temperature. Backside thinning is performed to remove the substrate which is absorbent in this spectral region and an antireflective coating is deposited.

2.3. First level of characterizations

To illustrate the homogeneity of the photoresponse of the detector, Figure 1 represents the responsivity measured with two blackbodies, 20°C and 35°C. The standard deviation of the latter is 1.8% over the full VGA format. The number of hard defects is only 28 pixels with a 30% criterion.

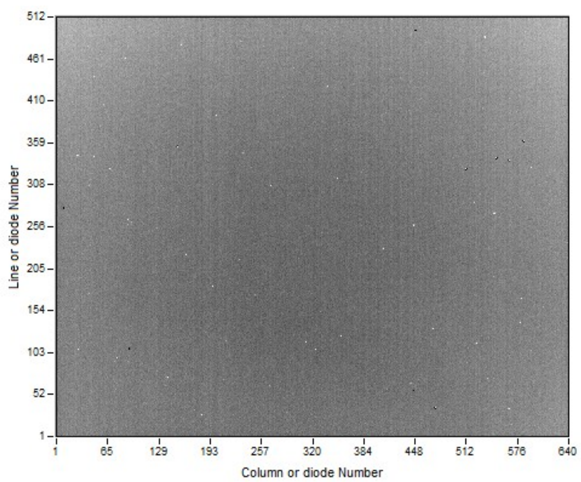

Figure 1: Responsivity measured with two blackbodies 20°C and 35°C.

Then, the Noise Equivalent Temperature Difference (NETD) is measured with a noise evaluated at 20°C and the responsivity presented in Figure 1. In Figure 2, the NETD histogram for the full MWIR VGA 15µm FPA is represented. The mean value of NETD is 28mK with a standard deviation of 7.5% and a perfect Gaussian shape of the histogram. The number of hard defects is only 46 pixels too with a 100% criterion.

The operability of the FPA is over 99.9% with 30 % DC level, 30% Responsivity and 100% Noise defect criterion.

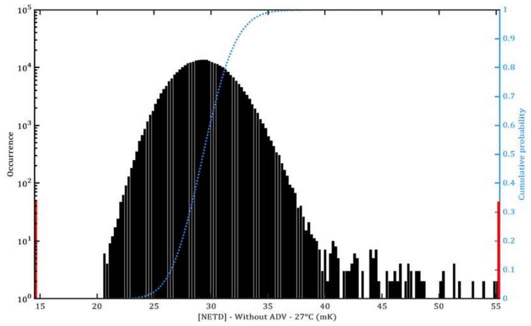

Figure 2: NETD histogram for a VGA 15µm pitch full MWIR detector, noise measured with a 27°C blackbody.

The mean dark current is equal to 1pA/pixel at 130K and the external quantum efficiency is evaluated to 70% over the spectral range of the band pass filter.

2.4. Image quality

In order to illustrate the image quality of an infrared focal plane array, the residual fixed pattern noise (HF RFPN) is used. This figure of merit illustrates the spatial local noise dispersion and its correctability. In Figure 3, HF RFPN is represented as a function of the blackbody (BB) temperature from -20°C up to 45°C. RFPN has been evaluated at a first cool down with a 2 points non-uniformity correction (NUC), represented in blue. Then four additional cool downs have been realized with an offset taken at the 25°C BB temperature. For the four last cool downs, the RFPN is perfectly reproducible. This figure of merit remains below unity in the whole BB temperature range and even below 0.6 for the positive BB temperatures. This point illustrates the high level of uniformity of this focal plane array (FPA).

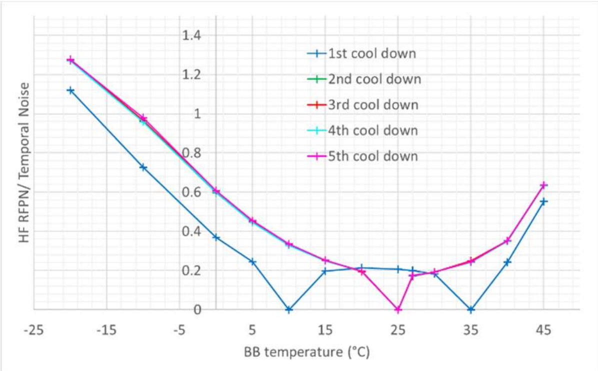

Figure 3: (Blue) RFPN over temporal noise as a function of the well fill with a two points NUC correction at a first cool down. Others: 2^{nd}, 3^{rd}, 4^{th} and 5^{th} cool downs with an offset correction at a 35°C blackbody temperature.

The number of HF RFPN defects with a three times temporal noise criterion is very low, below 200 pixels for BB temperature ranging from 5°C up to 40°C. The latter is constant for the three different cool downs.

The second figure of merit presented in this paper is the Modulation Transfer Function. The Modulation Transfer Function (MTF) is an important figure of merit as it accounts for the detector range. The MTF has been evaluated thanks to a knife edge setup. The MTF of the full MWIR VGA 15µm pitch FPA is represented in Figure 4. The value reported is the mean value over a large number of pixels of the FPA. A figure of merit to illustrate the MTF performance is the value at the Nyquist frequency which is highlighted thanks to the dotted lines. The MTF is equal to 0.48 +/- 0.01 at this frequency.

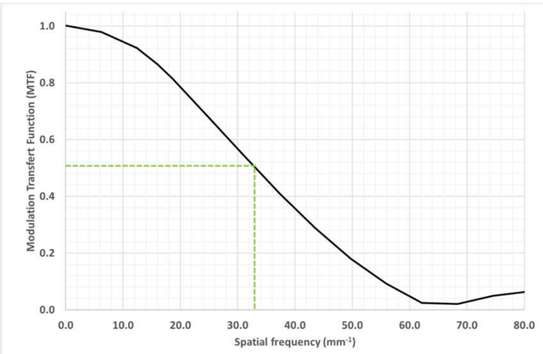

Figure 4: Modulation Transfer Function of the full MWIR VGA 15µm FPA.

3. FULL MID-WAVE INFRARED SXGA 7.5µM PITCH

3.1. Detector technological definition

This Focal Plane Array (FPA) has been developed and the first prototypes are available. It is addressing the full MWIR band thanks to an absorbing layer made out of T2SL. The characteristics of the T2SL are defined to reach a 5.1 +/- 0.1µm cutoff wavelength. This FPA is operating at a temperature of 130K and is characterized with a F/3 aperture. The cold filter is a [3.7, 4.8]µm band pass filter.

3.2. ReadOut Integrated Circuit & flip chip

A new Read Out Integrated Circuit (ROIC) has been designed by LYNRED. It is a digital ROIC with a SXGA (1280x1024) format and a 7.5µm pitch. The ROIC has been manufactured using an advanced Silicon CMOS foundry. As described in Table 2, the ROIC presents three different storage charges allowing many use cases of application. A very good linearity has been demonstrated in the whole well fill range. The power consumption in full frame at 130K is low, close to 100mW and a well suited frame rate of 60Hz for imagery in full format.

Table 2: SXGA 7.5µm pitch ReadOut Integrated Circuit characteristics.

	7.5µm pixel pitch ROIC
Format	1280x1024 (SXGA)
Integration modes	Snapshot - ITR/IWR
Storable charges	0.41Me-, 0.7Me-, 1.1Me-
Linearity	+/- 0.5%
Consumption	100mW (full frame & 130K)
Frame Rate	60Hz (full format)
Functions	Windowing, Line/row inversion, Image rotation, 2x2 bining

Post processing of the ROIC wafers is performed by LYNRED to allow the flip chip bonding using Indium bumps. This kind of flip chip is the best suited for a high yield and a good reliability. Backside thinning is performed to remove the substrate which is absorbent in this spectral region and an antireflective coating is deposited.

3.3. First level of characterizations

In order to illustrate the homogeneity of the FPA output, the responsivity in front of 20 and 35°C homogeneous black bodies is represented in Figure 5.This cartography highlights the low dispersion (1.7% standard deviation) of the responsivity for the 1280x1024 pixels. The number of defective pixels with a 30% criteria on the responsivity is 190, only.

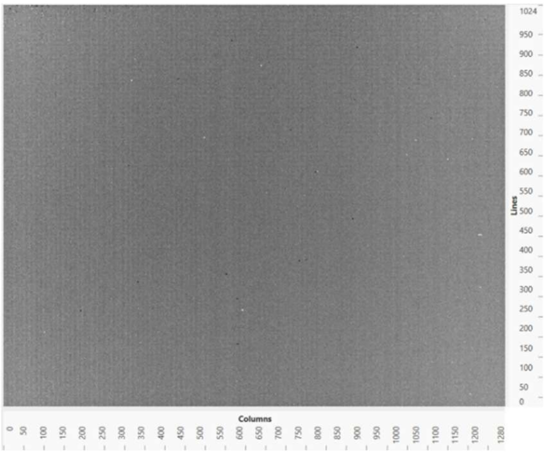

Figure 5: Responsivity cartography in front of 20 and 35°C homogeneous blackbodies.

3.4. Image quality

In order to illustrate the image quality of an infrared focal plane array, the residual fixed pattern noise is used. In Figure 6, the RFPN over the temporal noise is represented as a function of the blackbody temperature. At the first cool down (blue), a two points Non Uniformity Correction (NUC) is applied. RFPN/noise is significantly below between the two points correction.

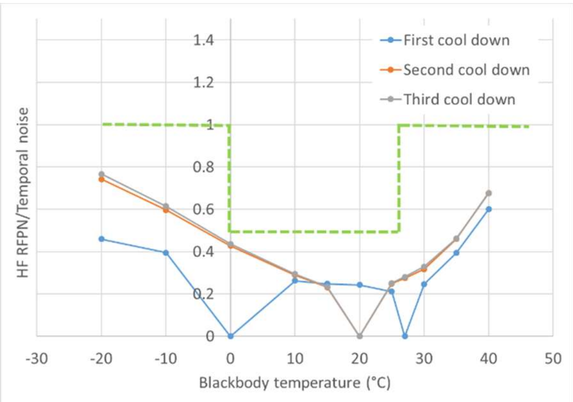

Figure 6 : (blue) RFPN over temporal noise as a function of the well fill with a two points NUC correction at a first cool down. Orange and grey, 2nd and 3rd cool down with an offset correction.

Then, two additional cool downs are performed with an offset taken at 20°C. The RFPN/noise remains lower than 1 on the full range of black body temperatures. In dashed green line is the objective, it is fulfilled.

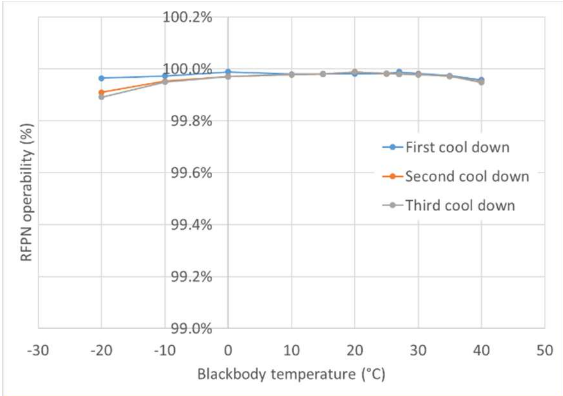

Figure 7: (blue) RFPN operability with a 3x temporal noise criteria at a first cool down. Orange and grey, 2nd and 3rd cool down.

Thanks to the same set of data, the performances in terms of operability are reported in Figure 7. Defective pixels are defined with a three times the temporal noise criteria. Still in Figure 7, this operability is extracted for the second and third cool downs. For the three different cool downs, the operability remains higher than 99.9%.

The blinking pixels are another category of defective pixels. A long acquisition of 5000 frames is realized in front of an homogeneous blackbody with a temperature of 27°C, then the number of pixels exciding a noise higher than three times the temporal noise criteria are detected. For this detector, the number of blinking pixels is 162 pixels.

The Modulation Transfer Function (MTF) is an important figure of merit as it accounts for the detector range. The MTF has been evaluated thanks to a knife edge setup. The MTF represented in Figure 8 is the mean value of a large number of pixels of the FPA as a function of the spatial frequency. The MTF at the Nyquist frequency is close to 0.40 which is the objective. The development is focused to improve this performance.

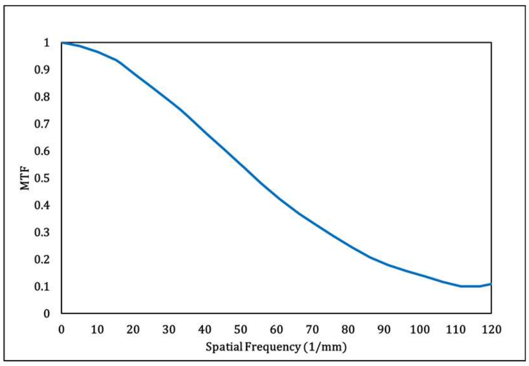

Figure 8: Modulation Transfer Function of the full MWIR SXGA 7.5µm FPA.

4. CONCLUSION

In this paper, two different FPAs have been presented. A full set of characterizations has been shared illustrating the latest development to address SWAP product using III-V material. This paper is focused on full band MWIR operating temperature at 130K. The state of the art performances like the residual fixed pattern noise and the MTF are illustrating the ability to reach a long-range detection. The low defectivity of the two FPAs is leading to a significant ease to integrate these devices in a system. The VGA 15µm pitch HOT MWIR detector is available for evaluation by the customers.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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