

High-performance uncooled amorphous silicon TEC less XGA IRFPA with 17 μ m pixel-pitch

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ABSTRACT

The high level of accumulated expertise by ULIS and CEA/LETI on uncooled microbolometers made from amorphous silicon enables ULIS to develop 1024 x 768 (XGA) IRFPA formats with 17 μ m pixel-pitch to address high end, high performance applications.

This detector has kept all the innovations developed on the full TV format readout integrated circuit (ROIC): detector configuration by serial link, two video outputs, low power consumption, wide electrical dynamic range... The specific appeal of this unit lies in the high image resolution it provides. The reduction of the pixel-pitch turns this XGA array into a product well adapted for high resolution yet compact systems. In the last part of the paper, we will look more closely at the high electro-optical performances of this IRFPA and the rapid performance enhancement. We will insist on NETD coupled with wide thermal dynamic range, as well as the outstanding uniformity and high pixel operability, achieved thanks to the mastering of the amorphous silicon technology coupled with the ROIC design. This technology node paves the way to high end VGA or 1/4VGA sensors as well as large diffusion compact smaller formats like 160 x 120 or smaller.

Keywords: Uncooled microbolometer, LWIR, 1024x768, XGA, amorphous silicon.

1 INTRODUCTION

ULIS has already demonstrated the capability to design detector answering main commercial and military applications. After the 45 μ m pixel pitch in 2001, the 35 μ m pixel pitch in 2003, and the 25 μ m pixel pitch in 2005, ULIS presented in 2008 a detector prototype of 1024 \times 768 with 17 μ m pixel pitch. This first prototype showed very promising performances [1] with mean NETD up to 85mK and dynamic range around 120°C. At the same time, a lot of effort has been devoted to improve this performance as it was expected [2].

The most recent development and the mastering of the a-Si:H technology have now allowed ULIS to reach much better performance levels both in NETD and Dynamic Range, as well as operability. In this paper, we will first review the current 25 μ m pixel pitch technology and in particular its thermal behavior and excellent operability. Then we will describe the new detector XGA with 17 μ m pixel pitch and show the improvement of the electro-optical performance results.

2 AMORPHOUS SILICON TECHNOLOGY

2.1 Background of uncooled amorphous silicon detectors

Amorphous silicon material used for uncooled infrared detector production benefits from a full set of very adapted physical properties and technology knowledge inspired from the microelectronics industry. The advantage of amorphous silicon is its direct ability to be monolithically integrated onto silicon CMOS substrates readout integrated

circuits. By pushing the design rules as afforded by well established step and repeat lithography, the amorphous silicon technology enables the manufacturing of detector arrays based on 25 or 17 μm pixel sizes, while maintaining the temperature resolution of the larger pixels of former generations. This feature promises dramatic improvement in system size and cost while keeping the thermal time constant as low as few milliseconds.

2.2 TEC-less ability

As the market needs are oriented not only towards higher performance but mainly on reduced size and low cost, ULIS has made a significant breakthrough in designing TEC-less detectors 160 x 120 or 384 x 288 with 25 μm pixel pitch [3]. The amorphous silicon, being a simple material, has a constant activation energy by physical principle all over the range of usual operating temperature. The variation <1% shown on Figure 1, over 110 $^{\circ}\text{C}$ range is mainly due to measurement error. Taking into account this unique behavior, TEC-less operation is considerably simplified and we have developed TEC-less detectors, the DC level of which is not saturated for large variation of ambient temperature [4].

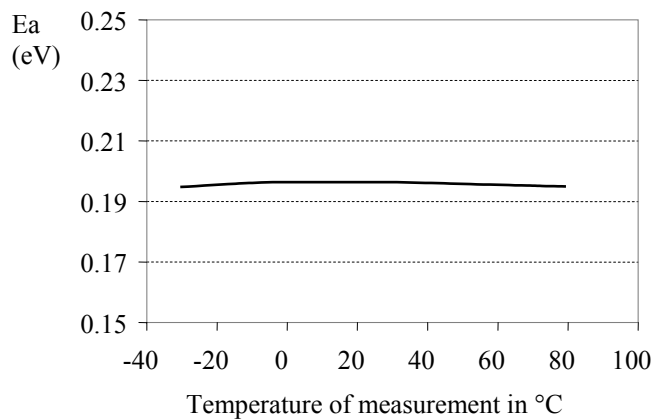


Figure 1: Measurement of the Activation Energy versus temperature of measurement

This behavior allows the user to operate this type of detectors over a wide range of ambient temperature without consuming energy for FPA temperature stabilization, with simple electronics along with limited mass memory to record NUC tables.

2.3 Operability

Other key point of the amorphous silicon is the very low number of defective pixels due to the simple silicon technology. Whatever the format or the pixel-pitch, we have shown that delivering detectors with operability better than 99.5% is not an issue.

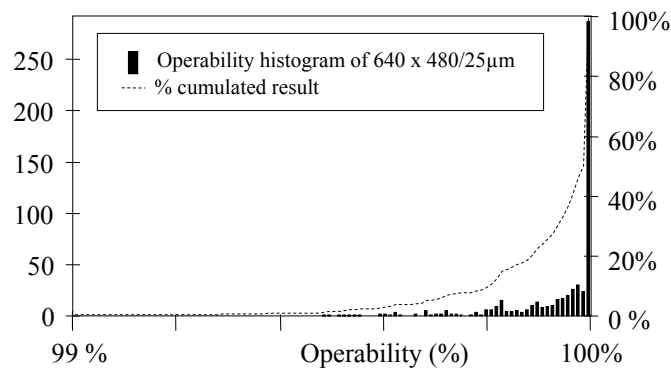


Figure 2: Operability on 500 delivered sensors 640 x 480 with 25 μm pixel pitch in 2009

Figure 2 shows the operability distribution of the 500 latest 640 x 480 with 25 μ m pixel-pitch. The cumulated percentage (dashed line) shows that the full sensor operability population lies over 99.5%. Moreover this curve shows that 80% of sensors present operability better than 99.9%.

3 XGA 17 μ m DEVICE DESCRIPTION

A readout circuit design has been developed for the 1024x768 detector. It enables extracting a faint signal from a high background current (see figure 3). The organization of the ROIC allows the integration of the microbolometer thermal signal after subtracting a common background current (skimming function), to sample and hold this information row by row and to multiplex the information to the output.

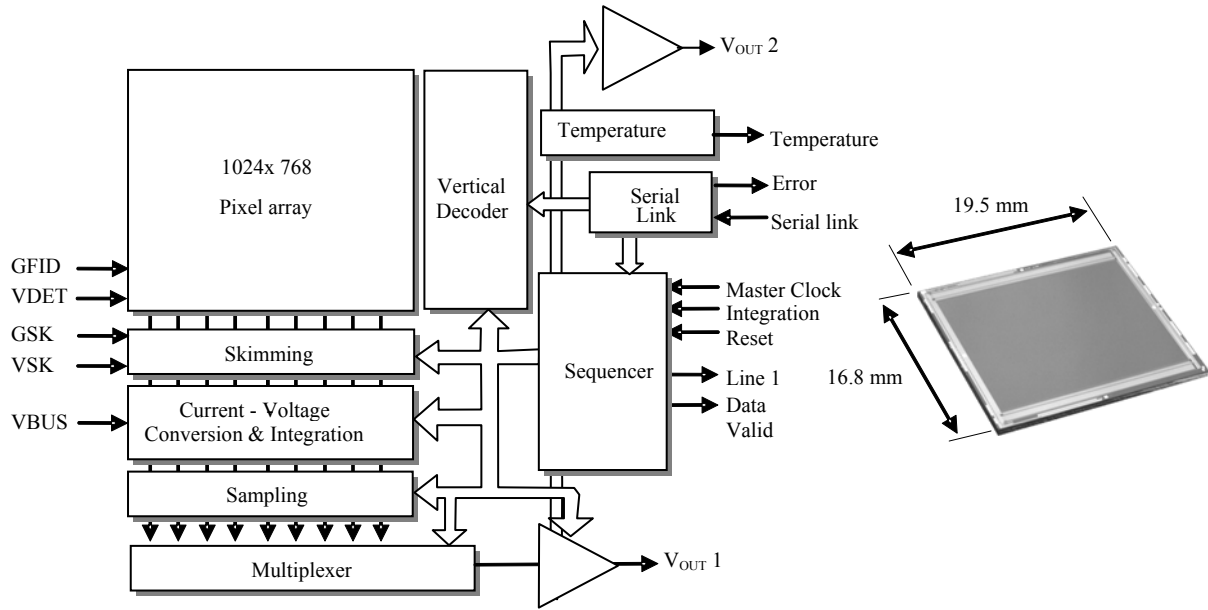


Figure 3: Readout circuit block diagram and silicon CMOS chip

This new ROIC requires 3.6 V voltage biases and therefore the electrical dynamic is ranging from 0.4 V to 2.3 V. Even with two video output amplifiers, this low voltage allows the detector to feature a very low power consumption of only 140mW for 30Hz video output. The pixels are pulse-biased row by row. The array can be read at a frequency higher than 30Hz. A windowing capability enables faster frame rates on reduced image format. This detector keeps profit from the previous ROIC designed for the 640 x 480 with 25 μ m pixel pitch and leads to an easier driving electronics development. A serial link enables to drive the gain, the windowing (format and position) and to flip the image reading direction (vertical and horizontal). These parameters are addressed using a 53 data bits word. At switch-on, the array is in a default configuration regarding gain, video output number and image scan direction. The table below gives the accessible parameters and their variation range.

Function	Nb of bit	Comment
Start	1	Indicates data word availability
Reserved	9	
CTIA gain	2	Range from 1 to 4
Vertical image flip	1	Up to Down or Down to Up
Horizontal image flip	1	Left to Right or Right to Left
Windowing	2	1024 x 768, 640 x 480, 320 x 240 or user defined window
Y_{first}, Y_{last}	2 x 10	Coordinates of min and max Y of the user defined window
X_{first}, X_{last}	2 x 19	Coordinates of min and max X of the user defined window

Table 1: Data word composition

4 ELECTRO-OPTICAL TESTS

All electrical and electro-optical tests are defined and carried out with $f/1$ optical aperture, a background temperature at 300 K, and FPA operated at room temperature. The two video outputs allow the detector to be operated at 30Hz frame rate with 12.5MHz master clock and $41\mu\text{s}$ integration time. Among ROIC possibilities, our choice was to set the CTIA gain at 2. Figure 4 shows the responsivity distribution. The mean value is 15.5 mV/K with σ/m as low as 1.99%. This very high responsivity uniformity is the result of the silicon technology behavior of amorphous silicon technology. The electrical dynamic range extends from 0.4 V to 2.3 V which corresponds to a temperature dynamic range at approximately 50 K.

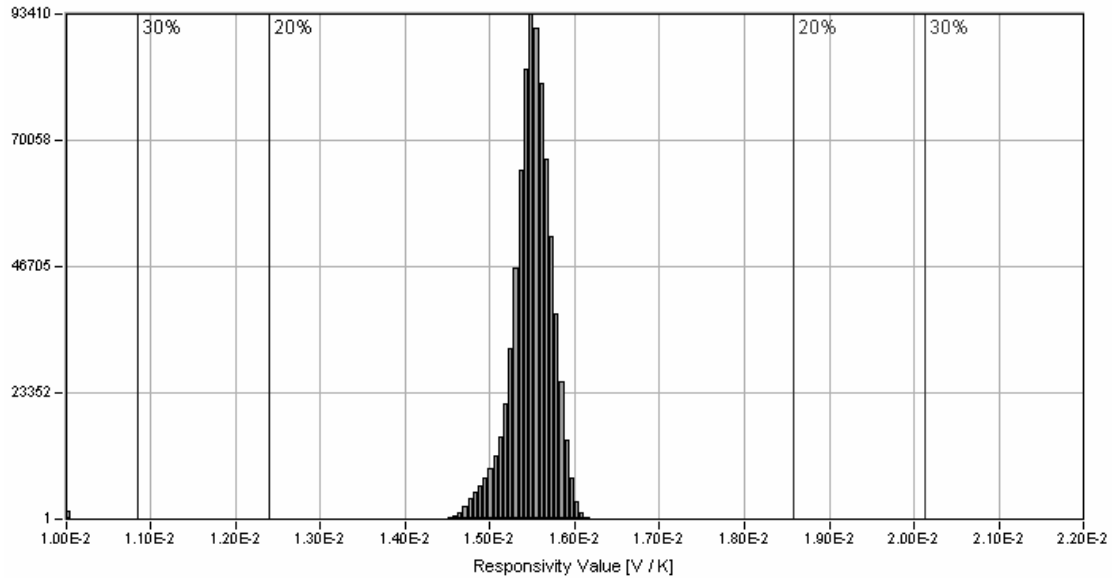


Figure 4: Responsivity distribution

Figure 5 shows the NETD map. The mean NETD is 40 mK with a standard deviation below 11 mK.

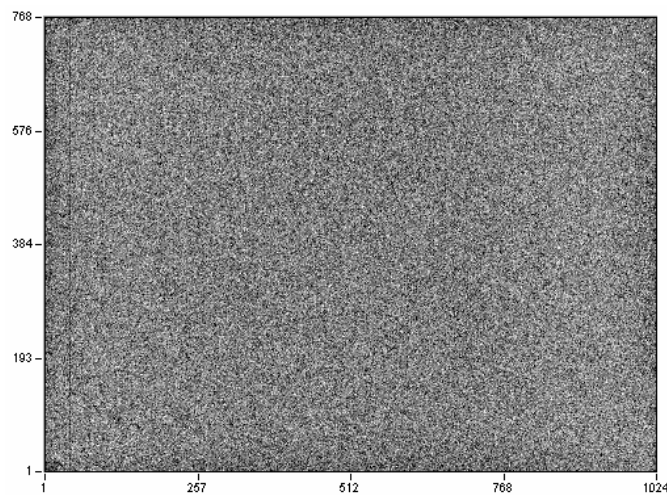


Figure 5: NETD map

Only 0.32 % defective pixels are present on this detector. The operability of the first tested 1024 x 768 batches, shows a mean value exceeding 99.5%. This high operability rate is similar to silicon CMOS APS sensors developed for digital still cameras.

The stability of amorphous silicon technology versus temperature allows the detector to be used at different temperature while keeping high performance NETD. Figure 5 shows the NETD stability versus temperature.

Taking profit from the simple technology (only one suspended level over ROIC), the limited thermal time constant (< 11 ms) enables to image fast moving objects at a relatively high frame rate.

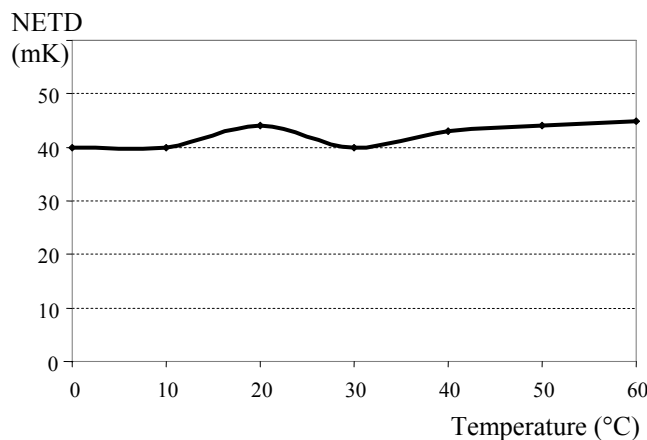


Figure 5: NETD versus FPA Temperature

It is possible to increase the dynamic range considerably by setting the CTIA gain, while offsetting the NETD slightly. This trade off is illustrated in the following table.

CTIA Gain	NETD (mK)	Dynamic range (°C)
2	40	50
1	47	170

Table 2: Electro-optical characteristics of standard 1024 x 768 with 17 μ m pixel pitch

5 CONCLUSION

In 2008, the first 1024 x 768 arrays with 17 μ m pixel-pitch has demonstrated highly uniform performance. The first prototypes paved the way to the R&D improvement program to achieve now NETD of 40mK coupled with a temperature dynamic range around 50°C. Limiting the detector gain expands the dynamic range to 170°C with 47mK NETD, thus opening any High End applications. A 640 x 480 with 17 μ m pixel size is under development to address applications currently limited by 320 x 240 available format. This VGA device will implement a 14 bits AD Converter and can be integrated in smaller package for keeping the compactness required by system integrators.

For low end applications, taking profit from this small pixel size, future detectors with small array sizes from 320 x 240 to lower than 160 x 120, will allow larger number of dies per wafer, leading to decrease the chip cost and to develop more compact systems.

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