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Further developments of 12µm pixel dual waveband MWIR-LWIR infrared detectors using MOVPE grown MCT

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ABSTRACT

Having established production capacity for high resolution, small pixel Mid Wave Infra-Red (MWIR) devices down to 8µm; this paper discusses the latest developments at Leonardo UK with 12µm MWIR-LWIR Dual Waveband Infra-Red (DWIR) high-performance infrared detectors, grown by Metal Organic Vapour Phase Epitaxy (MOVPE) on GaAs substrates. As with the 30µm, 24µm and 20µm mesa pixels that Leonardo UK pioneered during the early 2000's, the 12µm devices use a "back-to-back" diode arrangement, whereby the waveband is selected by changing the bias polarity across the diode stack; thus ensuring spatial coherence between the two wavebands. The increased thickness of DWIR MCT compared to single-band material makes manufacturing the mesa structure, in order to control inter-pixel crosstalk increasingly challenging with smaller pixel pitches. Previous publications by Leonardo UK presented results of 12µm DWIR technology on a 24µm Readout Integrated Circuit (ROIC), allowing only 25% of the pixels to be assessed; in this paper, we discuss results of this material on a 12µm ROIC, enabling assessment of 100% of the pixels. Low defects together with near Background Limited Infra-red Photodetector (BLIP) performance demonstrates significant progress towards the manufacture of higher resolution, lower cost DWIR devices by Leonardo UK.

1) INTRODUCTION

Leonardo UK have a mature and fully productionised process of growing Mercury-Cadmium-Telluride (MCT) detectors via Metal Organic Vapour Phase Epitaxy (MOVPE) on GaAs substrates. GaAs substrates typically offer greater mechanical strength, easier nucleation, and easier removal after device hybridisation, as well as being low cost compared to alternatives such as CdZnTe, Si and CdTe:Si. The MOVPE growth process allows detectors that operate in short, mid, long infra-red (IR) wavebands to be grown on the same GaAs substrates using layers of CdTe and HgTe. These discrete layers then diffuse together to form CdHgTe as part of an Interdiffused Multilayer Process (IMP) to form the MCT wafer. Controlling the relative thickness of the layers and the amount of doping allows the cut-on and cut-off of the material to be finely controlled. Mesa structures are then dry-etched into the CMT and the sidewalls are passivated, isolating neighbouring pixels on the array. The pixel pitch size of MOVPE-grown MWIR arrays is now down to 8µm, in a full production capacity [1], as shown in Figure 1.

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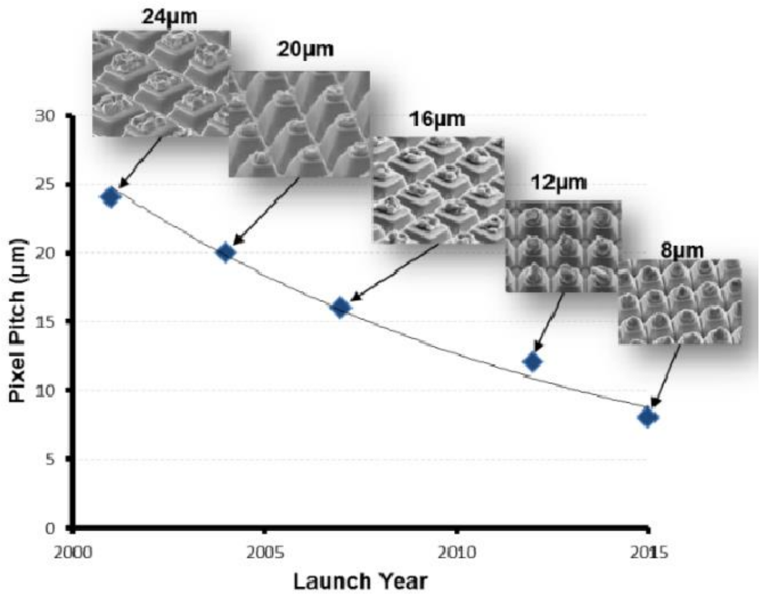

Figure 1: Evolution of MOVPE-grown MWIR Array Pixel Size

2) DWIR DEVICES ON MOVPE MCT STRUCTURES

The MOVPE-IMP lends itself well to building spatially coherent Dual-Band MCT detectors [2,3]. Figure 1 shows a simplified diagram of a MWIR-LWIR DWIR pixel. Each pixel consists of back-to-back p-n junctions. The p-type barrier layer composition and doping are selected to prevent transistor action, and the respective absorber regions are optimised to achieve the target wavelengths in the MWIR (3.7µm-5µm) and the LWIR (8µm – 9.4µm) in the example shown. Adjustment of the absorber regions would enable other combinations, such as MW-MW DWIR – where isolating different portions of the MWIR band is useful in applications such as missile warning systems. The Mesa structure and passivation is also illustrated, and the single indium bump contact to the ROIC. When a voltage is applied across the device, one of the junctions will be in reverse bias and the other in forward bias; photocurrent from the absorber that is adjacent to the reversed biased p-n junction will appear in the external circuit. This means that driving a bias voltage in either direction allows either MW or LW imaging with spatial coherence. The structure allows a rapid change between MW and LW operation, which allows near-temporal coherence when an interleaved readout sequence is employed.

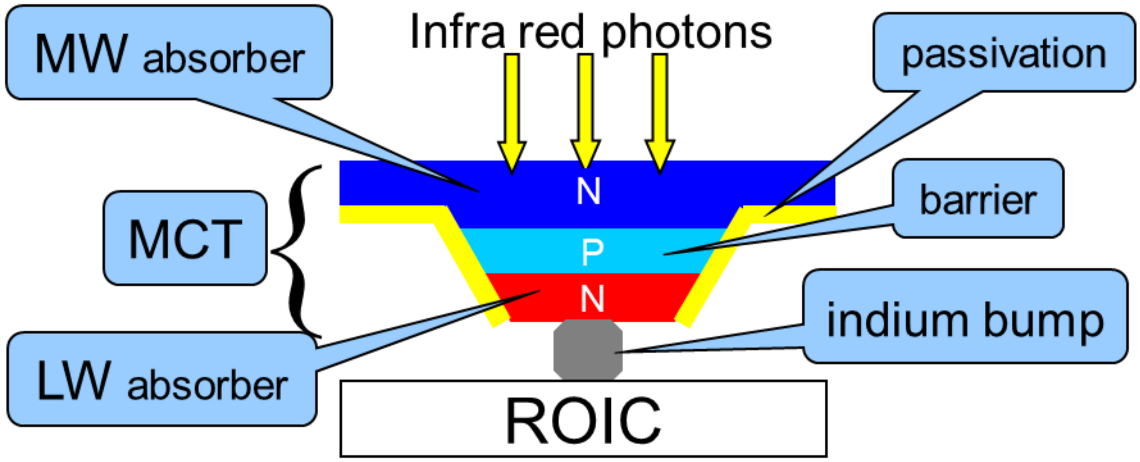

Figure 2: A Single MOVPE-Grown DWIR Pixel

3) DEVELOPMENT ON 12µM MW-LW DWIR ARRAYS

Leonardo UK has previously reported early test results on 12µm MW:LW DWIR arrays in 2019, and the rationale behind the need to reduce the pixel pitch down from 20µm-24µm DWIR arrays seen in detectors such as CONDOR II, CONDOR III and CONDOR IV [4]. Inevitable increases in MCT thickness when manufacturing DWIR arrays compared to single-waveband devices; means driving to smaller pixel sizes with a mesa structure is significantly more difficult from a processing perspective. This is primarily due to the need to etch deeper slots in a DWIR structure, whilst still keeping a large enough mesa top area for an indium bump contact. The 1280 x 1024 12µm CMT arrays presented in [1] were hybridised to a 24µm ROIC, only allowing assessment of 25% of the pixels on the array, which significantly limited the amount of EO characterisation, and process feedback. There are also inevitably concerns that surrounding a single connected pixel with eight unconnected pixels will cause interference with the measurement.

For the results presented in this paper, Leonardo UK have utilised the FLIR-1308 ROIC as a test vessel for Leonardo UK 12µm CMT arrays - allowing assessment of the full 1280 x 1024 array, in both wavebands. The hybridised focal plane array (FPA) has been mounted into a CONDOR-II Dewar (Shown in Figure 2), making use of the pre-existing capability this Dewar has in housing MW:LW DWIR arrays.

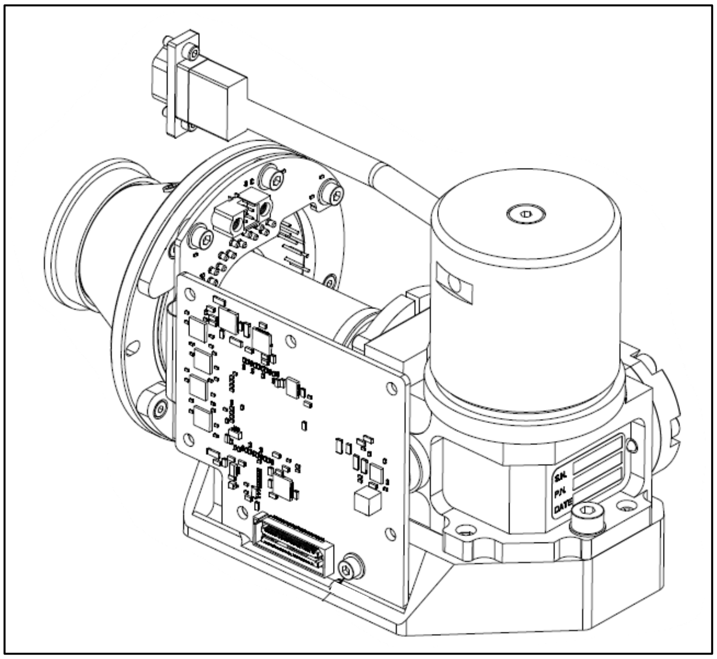

Figure 3: 12µm DWIR Demo Detector

There have also been several growth iterations to the MW:LW DWIR MCT structure since 2019 to improve array performance. The Mesa depth into the MW absorber region is significantly deeper, improving pixel-pixel isolation and thus reducing crosstalk, and refinements have been made to the LW absorber region to reduce leakage current. The p-type barrier layer composition has also been modified to make the diodes less vulnerable to transistor action, which increases noise in the imaging system.

The preliminary detector test results are reported in Table 1. The metric $NETD/NETD_{BLIP}$ is the ratio of the Noise Equivalent Temperature difference (NETD) and the theoretical NETD that would be purely Background Limited (BLIP). Defects are characterised as pixels that exceed 3 times $NETD_{BLIP}$, or pixels that have a photon flux response that is +/- 25% outside of the median value. Signal efficiency describes the conversion of photon flux to electrons.

Waveband (µm)	Integration Time (ms)	$NETD/NETD_{BLIP}$	Defects (%)*	Signal Efficiency (%)
MWIR (3.7-5)	16.5	1.15	1.7811	46.79
LWIR (8-9.4)	0.7	1.05	0.32814	56.17

Table 1: 12µm DWIR Results at Detector Level

Compared to Previously reported results [1], has significantly improved, along with the overall level of defects. The signal efficiency of the LWIR is much closer to the >65% seen on 24µm standard production DWIR, and the level of defects are comparable. Considering the array has a fourfold increase in pixel density, and the challenge in processing much thicker DWIR structures - this poses a significant advancement in Leonardo UK’s DWIR array capability, providing an EO performance that would meet most application demands. A reduction in the absorber thickness (compared to previous wafers) has resulted in photodiodes with a much higher dynamic resistance. Despite still achieving a good NETD and respectable defect levels, the MWIR layer requires some minor development, due to the lower than expected signal efficiency that should be nearer 70%. Preliminary spectral cross talk measurements from MW into the LW have been measured be around 3%.

Figure 3 depicts the first images produced by a 12µm 1280 x 1024 DWIR array. Some defect concealment algorithms have been applied to the MW image, but the LWIR image is uncorrected. The subject of the image is holding an acetate film, which absorbs LWIR, but transmits MWIR.

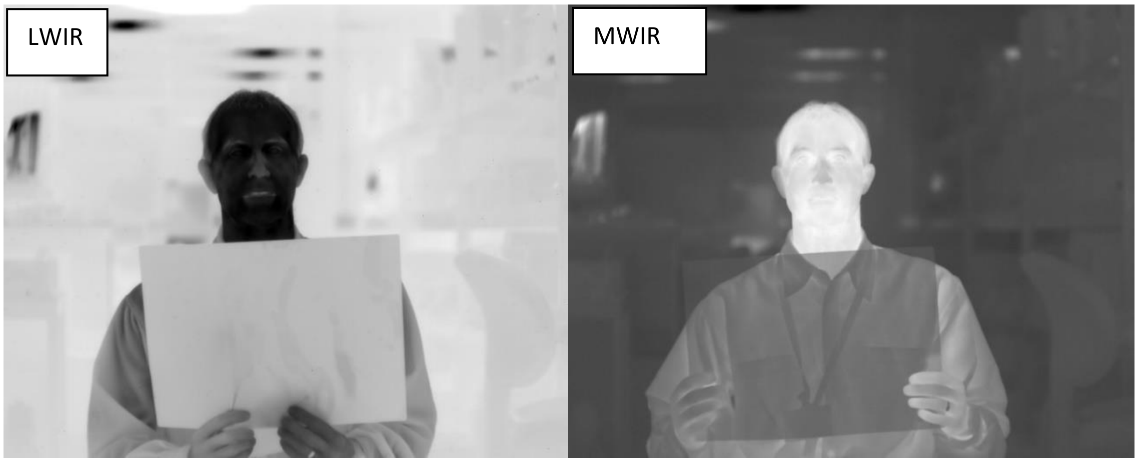

Figure 4: Lab-Based Imaging Trial of LWIR and MWIR operation

4) DEVELOPMENT DETECTOR AND CAMERA SYSTEM

In order to further showcase the performance of the 12µm DWIR MCT array, Leonardo UK have assembled an SLX DWIR Thermal Demo Camera with a manually focussing lens. The Camera has the ability of providing up to a 3-point NUC thanks to an in-built reference paddle. Similarities in hardware to the well-established 12µm HOIZON MWIR camera, will serve as a performance benchmark for the DWIR demo camera.

Figure 5: The SLX DWIR Thermal Demo Camera

5) CONCLUSIONS

Leonardo UK have successfully manufactured MOVPE grown 12µm DWIR MCT arrays, and have hybridised them to the FLIR-1308 ROIC as a test vessel, in order to carry out a full performance assessment of a 1280 x 1024 Array. Despite the challenges that come with processing thicker DWIR structures at finer pitches, the EO performance and defect levels achieved, particularly in the LWIR are in-line with the far more established 24µm-20µm structures that are currently in production. The MWIR still requires some refinement to achieve design aims, however, previous iterations of the DWIR 12µm CMT design have demonstrated MWIR signal efficiencies nearer to 60%, and sub-1% defect levels which would be suitable for production, so the route to a production ready 12µm SXGA DWIR MCT is well understood.

6) ACKNOWLEDGEMENTS

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