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Small Pixel MWIR Sensors for Low SWaP Applications

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ABSTRACT

Small pixel pitch sensors offer opportunities for imaging system SWaP reduction that open up a variety of SWaP-constrained applications that were not previously feasible. Furthermore, small pixel digital sensors provide advantages in the form of additional SWaP reduction, noise immunity, and simplified interfacing requirements. With these motivations in mind, Attollo Engineering has developed a 640x512, 5µm pixel pitch, high operating temperature MWIR sensor based on III V compound semiconductor detector materials. We have adapted our 5µm pixel pitch SWIR processes for MWIR detector materials and have been able to achieve 99.5+% operability MWIR FPAs with BLIP performance operating at 130K. Additionally, we have developed a compact camera core with an integrated cooler and full featured camera electronics. The global shutter camera is capable of frame rates of up to 220 Hz or smaller windows in excess of 1 kHz and integration times as low as 100 nanoseconds. Attollo will discuss characteristics of this sensor and other related technologies.

Keywords: MWIR, small pixel, IDCA, SWaP, superlattice, T2SL, SLS, nBn, HOT

1. INTRODUCTION

Attollo Engineering, LLC is a small business located in Camarillo California, about halfway between Santa Barbara and Los Angeles and located in the so-called Infrared Corridor along Southern California's coastline. We are an R&D and manufacturing company with a 34,000 sq. ft. facility that includes labs and a 2,500 sq. ft. cleanroom. The majority of our employees are design and process engineers along with technicians, and 9 employees who hold Ph.D. degrees related to fields in semiconductors and infrared. The company was founded in 2012 by Michael MacDougal and has been developing solutions for infrared systems ever since. The manufacturing and quality system at Attollo has been AS9100 certified since March of 2019.

At the core of Attollo's products is the intersection of infrared imagers, detectors, and lasers. With the increased use of lasers in military and industrial settings, we design the cameras to be able to sense those lasers, particularly short-pulsed ones. We design, fabricate, and assemble infrared imagers from the short wave to the long wave infrared with different sensing platforms in mind, such as soldier worn, vehicle mounted, as well as naval and airborne platforms. Our product portfolio spans a range of inter-related infrared sub systems, starting from laser rangefinders, SAL seekers, to warning devices, decoders, and beacons. The main objective of this paper is to introduce our cooled type-II superlattice based cameras, which play an integral role of sensing throughout the IR spectrum because of their flexibility in tuning their wavelength sensitivity.

Type-II superlattices, or T2SLs, is a III-V semiconductor epitaxially grown on GaSb substrates. The ability to grow this quantum system on the same lattice-matched substrate with layers of tunable band structure permits unique heterostructure designs that are formed with broadband spectral response, and beneficial device properties such as Auger and SRH reduction. Though the existence of T2SLs has been relatively short compared to MCT, it has seen rapid development in the past couple of decades and has demonstrated its ability to tune its wavelength broadly with good material and device quality. Attollo Engineering has subject matter experts with T2SL experience dating back to the early 2000s [Ref. 1-6], and therefore we are well equipped with T2SL design know-how. Shown in Figure 1 is a select number of antimonide detector spectra that Attollo has designed and processed, spanning from 3µm to 16µm in wavelength. Over the years, we have processed well over 100s of T2SL wafers up to 4" in diameter and have designed well over 30 epi structures spanning the different wavelength ranges shown. In the same figure are a few images taken with our focal plane arrays with sensitivity from the eSWIR to long wave infrared.

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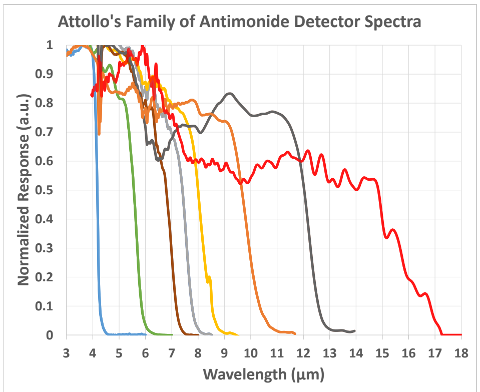
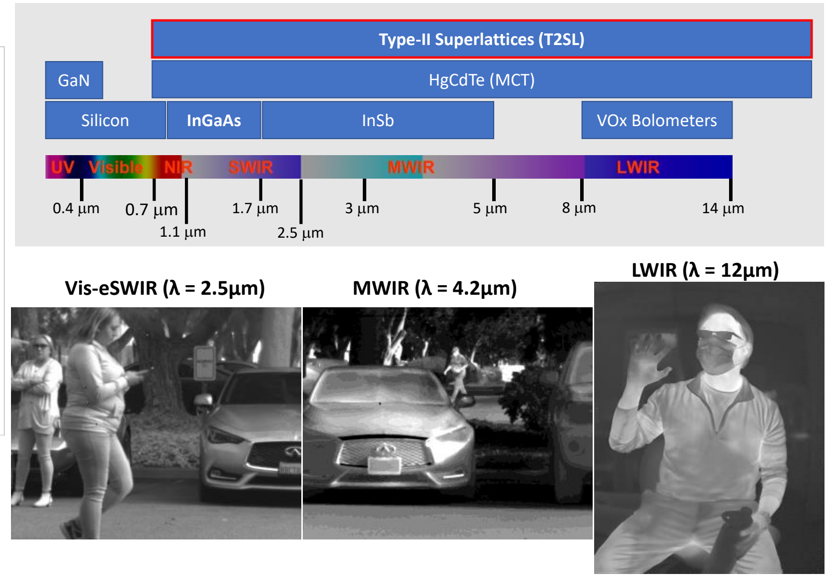




Well over 100s of T2SL wafers processed across various wavelengths (up to 4" diameter); designed over 30 epi structures and counting

Figure 1 - Attollo Engineering's Antimonide T2SL detector offerings spans the SWIR to VLWIR wavebands

2. ULTRAWIDE™ HOT MWIR T2SL DETECTORS

Attollo offers a unique product line of UltraWide™ mid-wave T2SL detectors. UltraWide™ mid-wave provides our customers with an extended response from the designed cutoff wavelength down to the near infrared range in back-side illuminated focal plane arrays. Our spectral measurements shown here on 4 um and 5.3 um cutoff detectors were measured on our FTIR, and therefore limited in its visible spectra measurement capability. We observe high and broadband quantum efficiency, where the QE is greater than 70%. This UltraWide™ design is not only applicable to our mid-wave cutoff detectors, but is also a feature of all of our T2SL detectors including those in the long-wave infrared. UltraWide™ mid-wave provides our customers with the ability to address use-cases where traditional mid-wave detectors may be limited. Such use-cases include seeing through glass and windows as well as sensing lasers in the Near and Short-wave infrared.

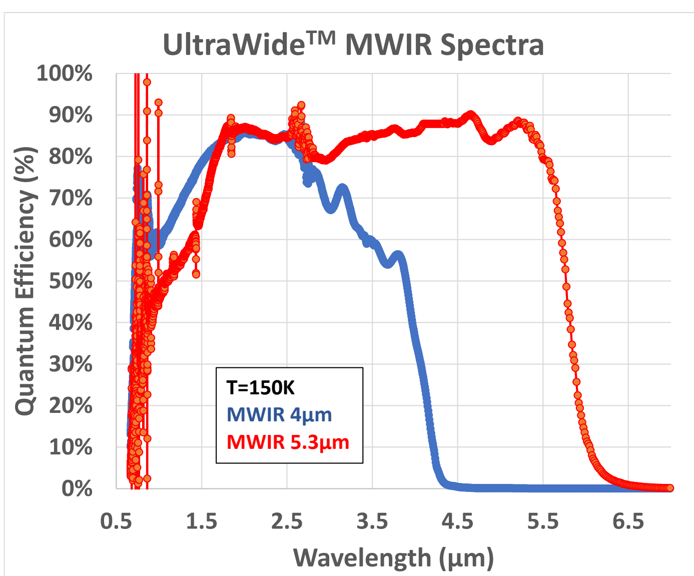
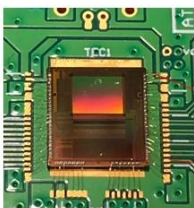


Figure 2 – UltraWide™ T2SL response extends down to 0.7µm

As you may recall from last year’s SPIE presentations, we had discussed 5µm pixel development on VGA format InGaAs focal plane arrays [7]. As a derivative of that work, a sister read-out integrated circuit with the same format and pixel pitch was developed with larger well capacity for the mid-wave infrared. This global shutter read-out features well capacities beyond 2 mega electrons through sub-frame averaging. With on-chip ADCs, this ROIC can also support up to 220Hz frame rate with 4 digital LVDS outputs. Because of the small 5µm pixel pitch, our VGA FPA measures only a few millimeters per side as shown on the bottom of Figure 3 compared to a U.S. quarter, allowing us to attain a thousand dies per 8” ROIC wafer. Similarly, on the detector side, we see 50 plus detector dies laid out on a 4” T2SL quarter wafer, and in principle, 200 plus detector dies on a full 4” wafer. The small form factor of the focal plane array has benefits not only in potential reduced materials cost, but also in the system-level size, weight, and power. The 5um pixel focal plane array lends itself to using shorter focal length and therefore more compact lenses, such as the 15mm optic shown in the figure. Smaller focal plane arrays also reduce the necessary heat loads not only from the focal plane itself, but also from other internal components within the dewar that are scaled down in size, thereby reducing power needed by the cryocooler.



Parameter	Value
Format	640 x 512
Pixel Pitch	5 µm
Max Frame Rate	220 Hz
Shutter mode	Global
Readout mode	ITR
Read noise	< 250 e-
Well size	~630 ke- / >2.25Me- (SFA)
Minimum integration time	< 1 µs
Digital LVDS outputs	1, 2, 4

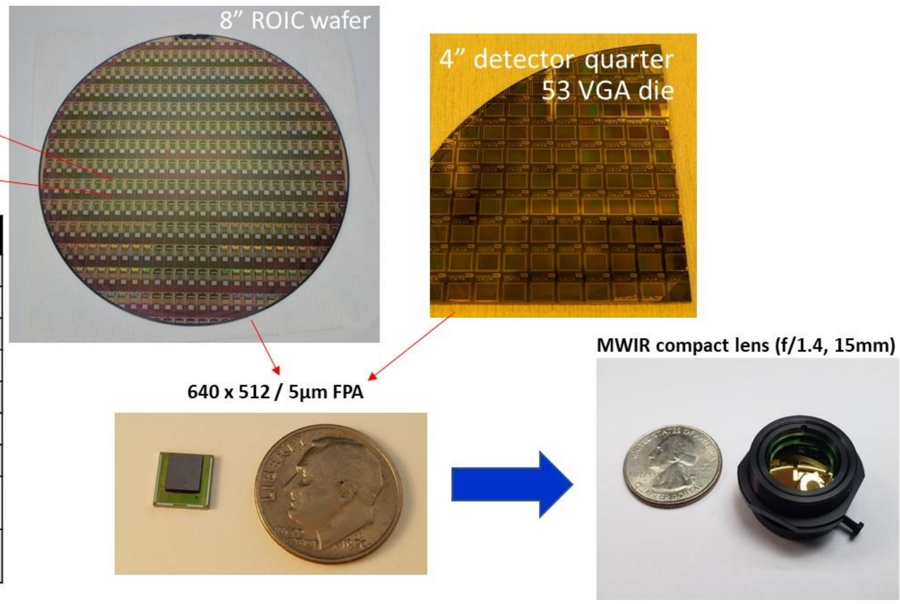


Figure 3 – 5µm pixel FPAs translates to direct system level SWaP benefits, e.g. shorter focal length / compact lenses and reduced heat loads, etc.

Figure 4 exhibits our 5.2um cutoff T2SL detectors operating at 120K. Shown in the figure are the NEDT maps and histograms of our 5um pixel FPAs. Across the FPAs, we see repeatable performance of less than 27mK in sensitivity and greater than 99.8% operability at 120K. They were tested with a cold shield f/# of 1.4, and at 50% well fill with a 20° C blackbody uniformly illuminating the FPA. These results show the general producibility of 5um pixel T2SL FPAs along with their good sensitivity and high operability.

As we elevate the FPA operating temperature even further, we expect the dark current to rise and reduce sensitivity performance. When we increase the temperature of our 5.2um detectors to 140K, we see a negligible rise in NEDT, while still maintaining below 32mK and an operability greater than 99.5% (Figure 4). This is an encouraging result as we consider very high operating temperatures to reduce system level power draw primarily from the cryocooler and to extend cooler operating lifetime.

Imaging results were obtained from our VGA format FPAs with 5um pixels as shown in Figure 5. We show video still captures with the FPA operating from 120K to 170K. The lens that we used is a 50mm lens with a f/# of 2.3 and transmission in the 3-5um waveband only. Although the lens is not optimized for 5µm mid-wave pixels, nevertheless we see the utility of the mid-wave images up to 170K, despite increasing the temperature and therefore dark noise of the pixels. But by in large, many of the pixels are still sensitive enough to identify walking human subjects, vehicles, and trees in the scene.

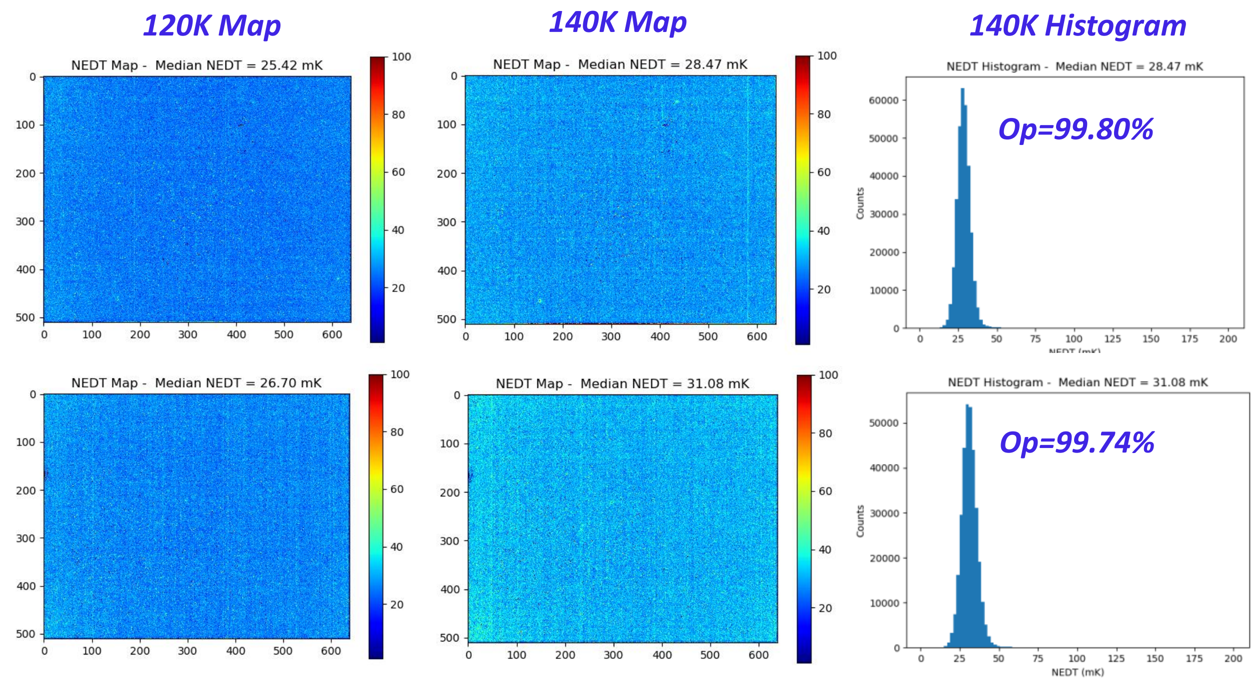


Figure 4 – VHOT MWIR (λ=5.2µm) 5µm pixel FPA performance @ 140K – NEDT < 32mK and Op > 99.5%

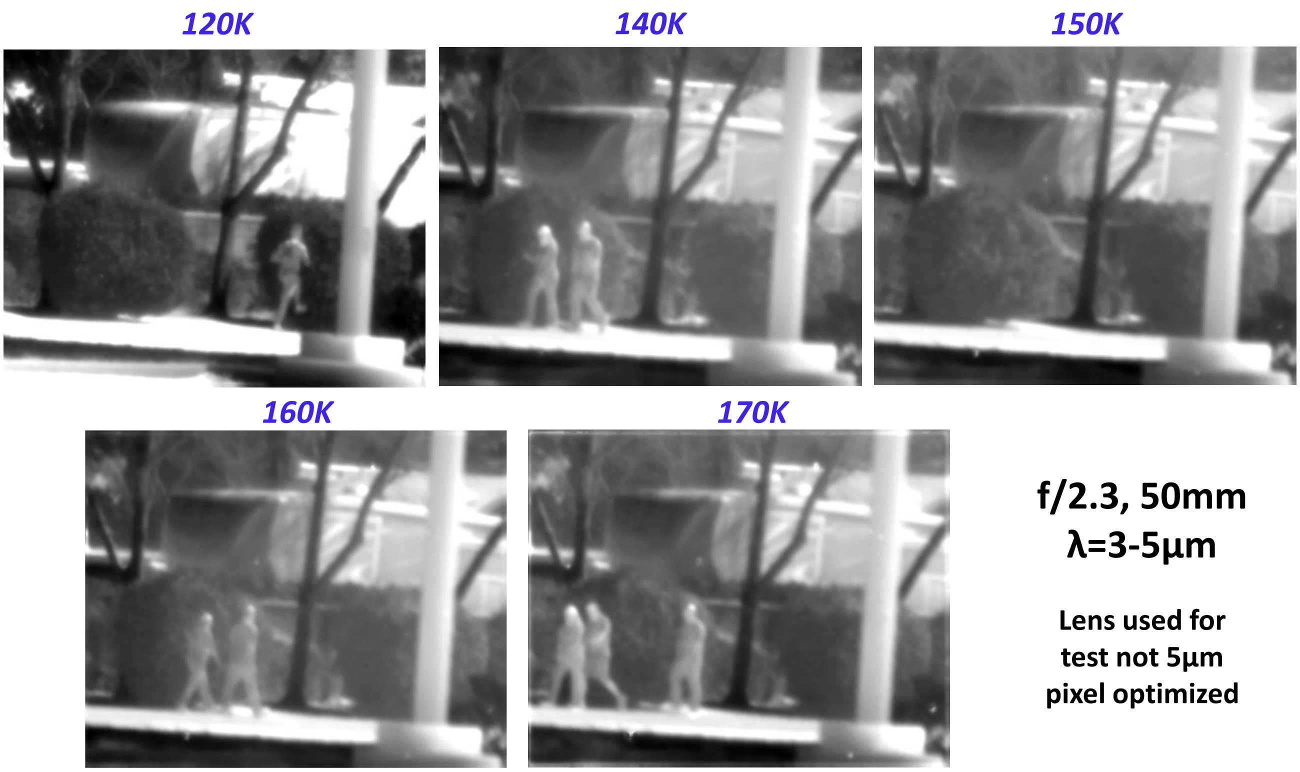
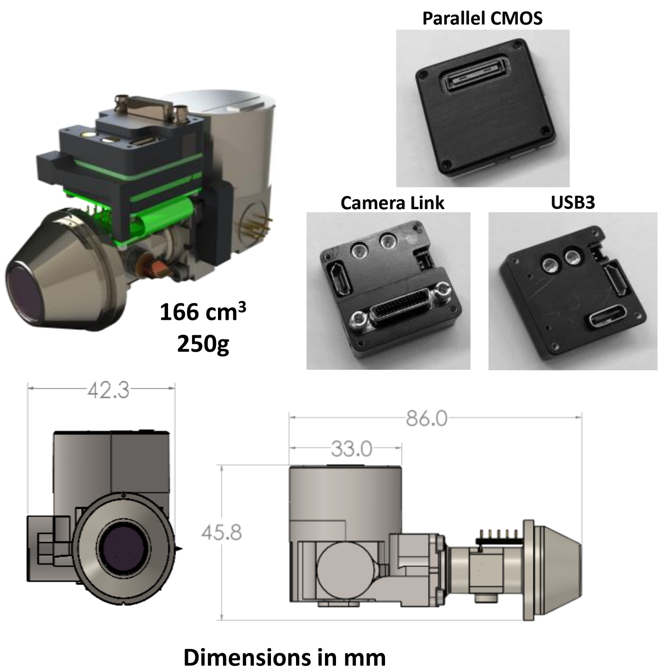


Figure 5 – VHOT MWIR (λ=5.2µm) 5µm pixel FPA imaging from 120K to 170K

3. GRIFFIN-5 HOT MWIR: LOW SWAP ROTARY IDCA

Attollo Engineering has taken our T2SL VGA format 5µm pixel pitch technology further by creating a low size, weight, and power camera core based around our FPA (Figure 6). The Griffin-5 HOT MWIR camera, where the number signifies the pixel size, is a rotary cooled IDCA that weighs 250 grams and has a volume of 166 cm^3. We offer variants in spectral response based on our UltraWide™ mid-wave, which provides a response down to 0.7 um, or the conventional 3-5µm spectral response. Notably, our camera electronics support sync in triggering, a sync out signal, and have on board video processing for non-uniformity correction, bad pixel replacement, AGC, etc. Shown in the center are the different options for video output interfaces to include parallel CMOS, camera link, and USB3. We are looking to make the Griffin-5 available to our customers starting in the 4th quarter of 2021 and a preliminary specification table is shown in the same figure.



Preliminary

Camera	
Detector Material	Type-II Superlattice (T2SL)
Spectral Response	3.0 – 5.2 µm Response down to 0.7 µm available
Array Format	640 x 512
Pixel Pitch	5 µm
F/#	F/1.8 F/1.4 available
NEDT	≤ 30mK
Operability	> 99.5%
Quantum Efficiency	> 70% (2-5µm)
Frame Rate	30 Hz, 60 Hz, 120 Hz, 220 Hz, Windowing
Imaging Mode	Global shutter
Integration Time	Presets and user-defined, minimum = 0.1 µs
Triggering	Sync-In (low-latency for see-spot & range-gating); Sync-Out
On-Board Processing	Non-uniformity correction; bad pixel replacement; AGC
Electrical	
Input Voltage	5V ± 10%
Power Consumption	≤ 4W steady state, 10W peak (during cooldown)
Video Output	Parallel CMOS, Camera Link**, USB3**
Command and Control	UART, I2C, SPI
Mechanical	
Dimensions	166 cm^3
Weight	250 g
Mounting	Clamp mounting/Custom
Lens Mount	Custom options available
Connector	HIROSE DF40-50

Griffin-5 availability in Q4 2021

Figure 6 – Griffin-5 HOT MWIR

As for the future of the Griffin-5 product, we are looking at ways to meet the needs of our customers by considering form factor, waveband, and resolution as variants to the Griffin-5 product line. By taking essentially the same dewar developed on the Griffin-5 rotary IDCA, we intend to offer a linear cooled version that has an approximate length of 61 mm, and a width no greater than 50 mm. This offering would be ideal for customers with stringent optical length requirements looking for payloads with the smallest form factor. We are also looking to broaden our 5 µm pixel portfolio to encompass long-wave infrared FPAs. In Figure 1, we have shown 12µm cutoff long-wave FPA imaging results on a larger pixel pitch operating at 76 K. Lastly, we see high resolution imagers become more attractive at smaller pixel scales, as the system level impact on the camera footprint is more manageable and favorable for SWaP with HD formats and small pixels.

4. PORTFOLIO OF DUAL-BAND T2SL DETECTORS

Beyond Attollo's Griffin-5 offering, we are working on a number of dual-band development activities related to T2SLs. One of the greatest qualities of T2SL detectors is undoubtedly the potential for band structure engineering, not only from the standpoint of creating improved detector performances, but also from a multi-band imaging perspective. In this case, we have taken our portfolio of single band detectors and created single contact sequential dual band sensors from them, whereby each band is selected by changing its biasing polarity. We have engineered eSW/MW, MW/MW, and MW/LW dual band detectors based on tunable T2SL heterostructures, where the normalized spectral responses are shown in Figure 7. While further optimizations are currently underway, we have already demonstrated dual band FPAs on small pixels as detailed in the next section.

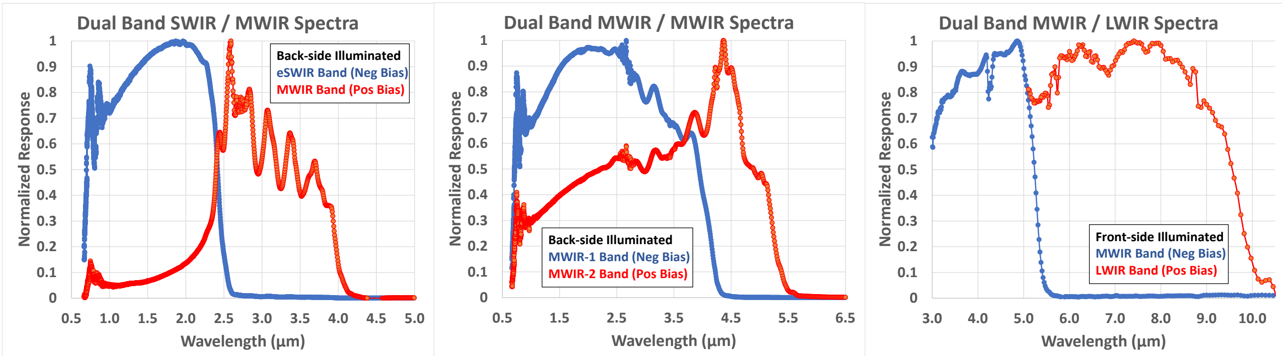


Figure 7 – Dual-band Detector Spectra

5. GRIFFIN-8 HD: DUAL-BAND HOT MW/MW HD720P / 8µM PIXELS

Attollo's foray into dual band T2SLs begins with our HOT MW / MW T2SL focal plane array operating at 120K. Our HD720p FPA is on a mere 8µm pixel pitch, making the fabrication of thick dual band detectors on a very small pixel pitch challenging. Our Band-1 mid-wave is based on our UltraWide™ mid-wave technology, spanning its response from 0.7 µm to 4 µm. Band-2 mid-wave has a spectral response primarily in the 4 µm – 5 µm range. As it is exemplified here, our UltraWide™ Mid-wave provides the ability to see through the car's window, where the position of the headrest is apparent, and the subject and his headphones as well, whereas in Band-2, the windows are opaque.

UltraWide™ MWIR-1 (0.7-4µm) **MWIR-2 (4-5.Xµm)**

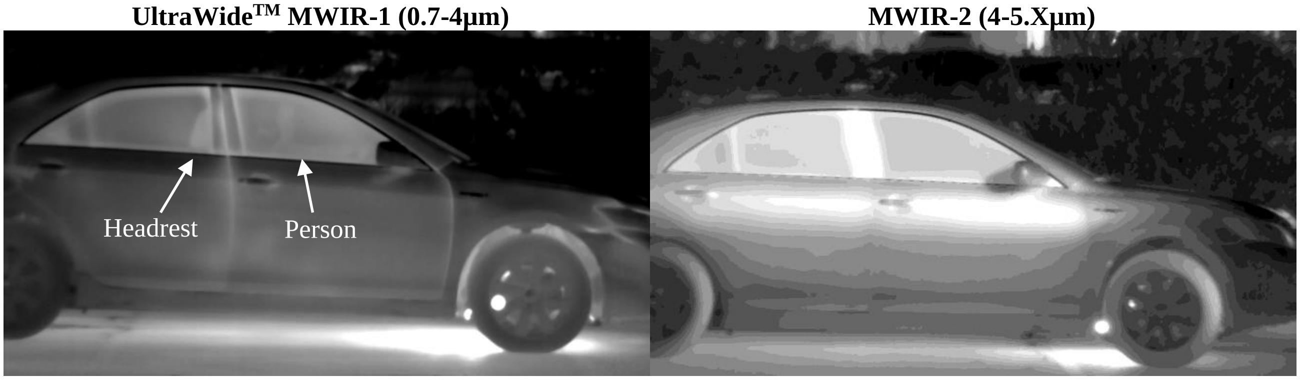
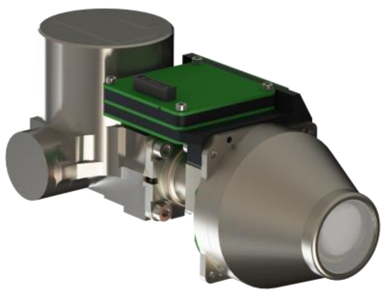


Figure 8 – Dual-band HOT MW/MW 8µm pixel FPA imaging at 120K

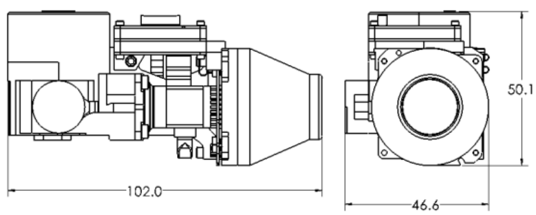
Our Griffin-8 HD camera is a dual band capable core operating at high temperature. Based on a HD720p / 8µm pixel FPA with digital outputs, the spectral bands offered will be 3-4 µm in Band-1, with UltraWide™ Mid-wave as an option, and 4-5.2 µm in Band-2 or with just a single color of either band. The physical dimensions and a preliminary datasheet are shown in Figure 8. The expected sensitivity is less than 30 mK in both bands with 99.5% or greater operability. The effective full frame rate is 250 Hz for dual band imaging. Compared to the Griffin-5, it offers greater dual band functionality with only a small increase in form factor. Other product variants include a SW / MW dual band core, which will become available at a later date. The Griffin-8 HD will become available in the 1st half of 2022.

Griffin-8 HD

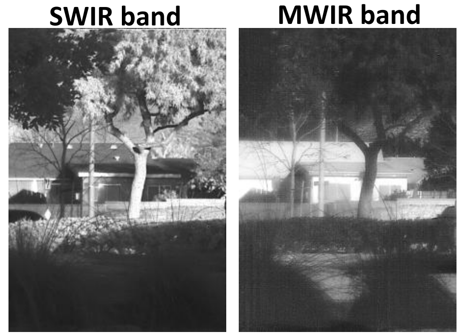


Preliminary

Camera	
Detector Material	Type-II Superlattice (T2SL)
Spectral Response	Sequential dual band 3.0 – 4.0 µm (Band 1, response down to 0.7 µm available) 4.0 – 5.2 µm (Band 2)
Array Format	1280 x 720
Pixel Pitch	8 µm
F/#	F/2.3 (other options available)
NEDT	≤ 30mK
Operability	> 99.5%
Quantum Efficiency	> 70% (2-5µm)
Frame Rate	Up to 250Hz
Imaging Mode	Global shutter
Integration Time	Presets and user-defined, minimum = 0.1 µs
Triggering	Sync-In (low-latency for see-spot & range-gating); Sync-Out
On-Board Processing	Non-uniformity correction; bad pixel replacement; AGC



Dimensions in mm



Griffin-8 HD Rotary IDCA available in H1 2022

Figure 9 – Griffin-8 HD: Dual-band MW/MW 8µm pixel Camera

To summarize, Attollo has introduced our two rotary cooled camera cores based on SLS detector technology. The Griffin-5, based on 5 µm pixels and a 5 µm cutoff, is an attractive HOT MWIR core with low-SWaP that will become available later this year. The Griffin-8 HD, is a HOT MW dual-band capable camera on a 8µm pixel pitch, that will be launched in H1 of 2022.

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