Electrophysics Resource Center:
Infrared Imaging

White Paper:
High-performance MCT Sensors for Demanding Applications

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Recent MCT Technology Enhancements Yield Improved Long-wave Infrared Imaging Performance for R&D Applications

Introduction

There are a growing number of infrared photovoltaic 2D focal plane array (FPA) detectors commercially available for integration into high performance infrared cameras. Sensor materials include indium gallium arsenide (InGaAs), quantum well infrared photodetector (QWIP), indium antimonide (InSb) and mercury cadmium telluride (MCT). In addition, microbolometers (µB) have also closed the performance gap with photovoltaic detectors, however significant performance differences remain. Proper selection of sensor technology depends on the application and systems requirements.

Over the past 15 years, InSb FPAs have reached commercial maturity and are now available in formats over 1Kx1K. These FPAs feature mid-wave infrared (MWIR) spectral responsivity and >90% quantum efficiency, and result in infrared imaging systems with thermal sensitivities under 20mK. While a significant number of military electro optical platforms have transitioned from scanned longwave infrared (LWIR) "common module" based sensors to mid-wave InSb based sensor engines, they are more commonly found on airborne and marine platforms where the 3-5 micron band works well in typical atmospheric conditions. On the other hand, ground-based infrared imaging platforms continue to rely on long-wave systems due to their performance under anticipated battlefield conditions.

Previously, systems designed for long-wave infrared imaging have had several options: integrated advanced linear arrays with time delay integration (TDI), microbolometer and QWIP FPAs. While these technologies deliver good performance, there are some limitations for R&D applications. TDI-based systems, for example, lack the ability to perform simultaneous (snap shot) integration, variable frame rate and variable integration settings. Microbolometers offer wide spectral response (7-14µm) but exhibit lower thermal sensitivity (typically >50mK), require fast optical designs (~ƒ1.0-1.5) and have long thermal time constants that limit frame rates to 60 frames per second. QWIP-based systems offer higher thermal sensitivity but have low quantum efficiency.

Despite the higher cost of MCT-based LWIR systems when compared to low cost microbolometer systems as well as QWIP-based systems, infrared imaging systems based on MCT LWIR detectors have several important advantages.

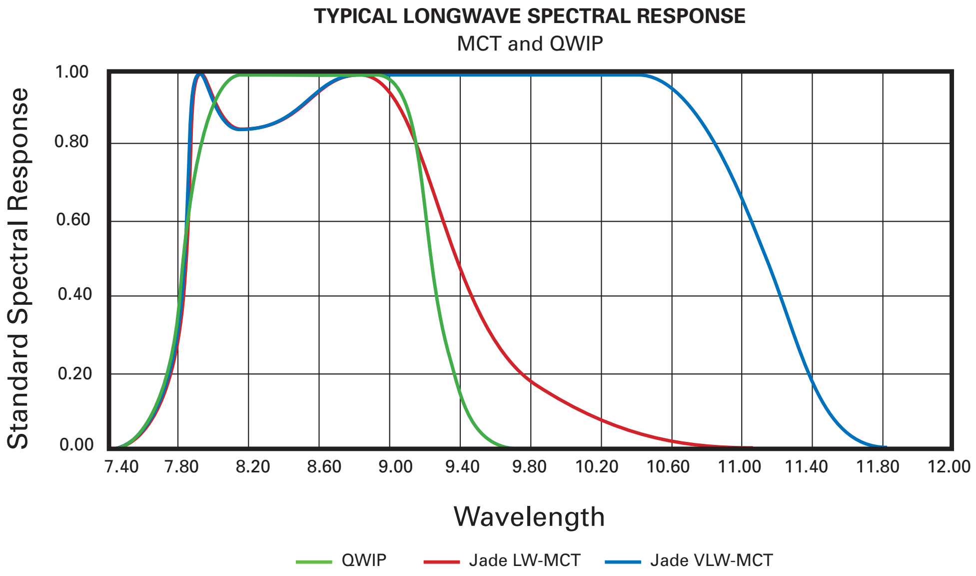
Recent advances in MCT FPA fabrication has led to the commercial availability of MCT-based infrared imaging systems with long-wave spectral responsivity, good uniformity, higher operability (>98%) and broader spectral responses.

Currently available MCT LWIR arrays provide spectral response from 7.7-9.5μm and extended response (beyond 11 microns) are being delivered in limited quantities.

Advantages of LWIR Imaging

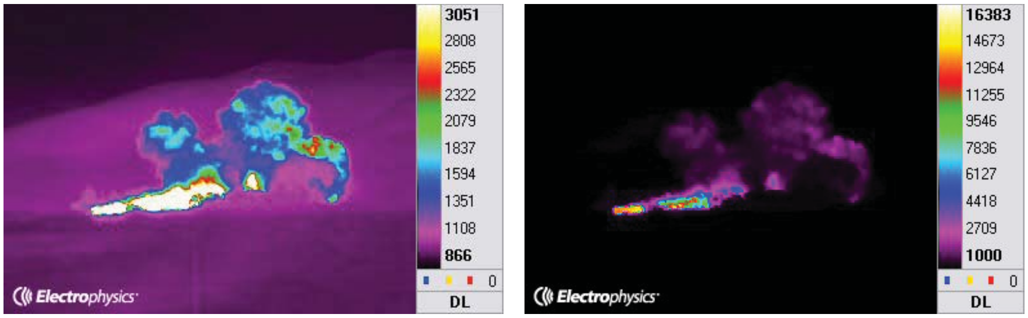
MCT-based infrared imaging systems offer several key advantages over other sensors for certain applications. Most obvious is that many applications require imaging in the long-wave infrared spectral band (see Figure 1). These include spectroscopy, laser beam profiling, target signature analysis and phenomenology, all requiring spectral response around 10μm and high interband sensitivity.

Figure 1: Normalized Spectral Response for Qwip, LW-MCT and VLW-MCT



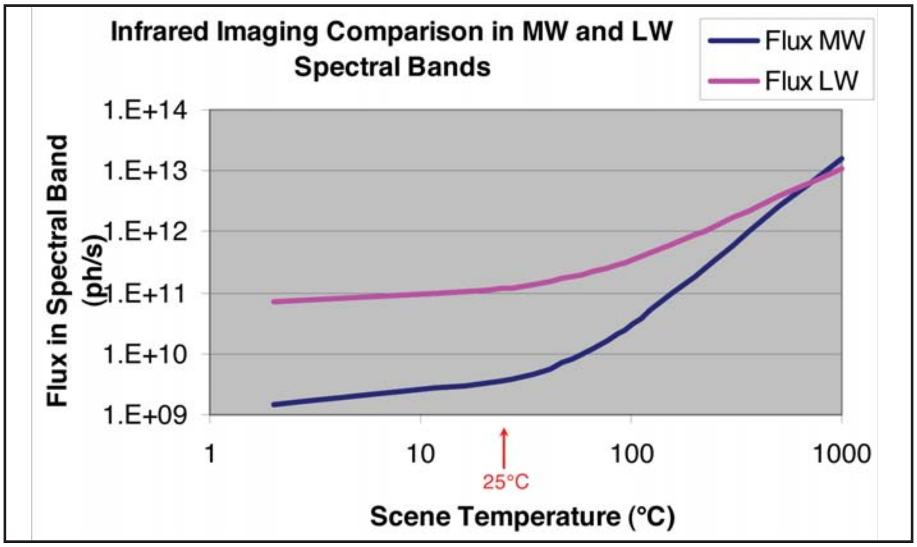
In addition, a high performance LWIR system also offers a very broad dynamic range capability. Specifically, this is important in those applications in which the object of interest spans a very wide temperature range. As an example, Figure 2 shows an image sequence from the test firing of a solid rocket booster.

Figure 2 – Test Firing of Solid Rocket Booster:
Sequence shows the wide intra-scene dynamic range of an LWIR infrared imaging system able to produce valuable imaging data at both the background temperature as well as the plume temperature. Rocket plume ~2500K; ambient temperature ~260K. Images were obtained with a Jade LW-MCT.



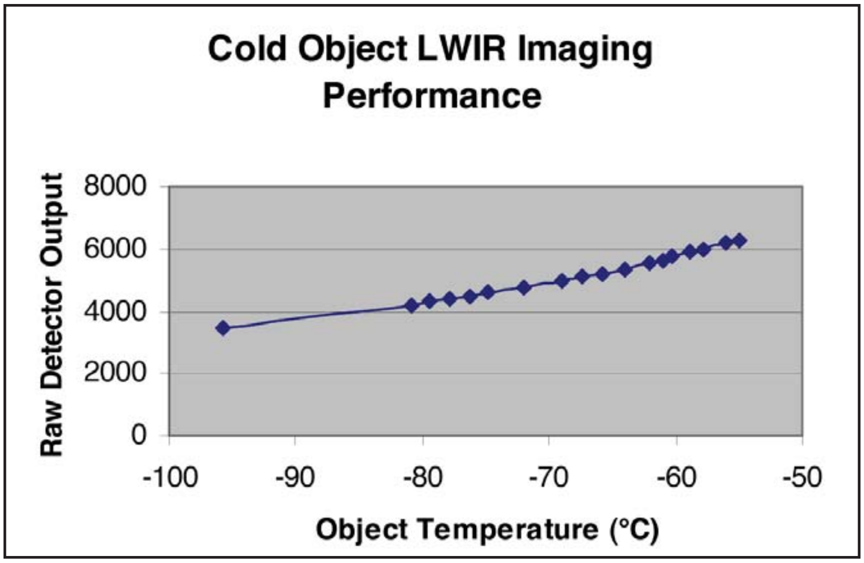
Such an extended intra-scene dynamic range would not be possible with an MWIR system. The impressive performance of the MCT LWIR System is easily explained by comparing the flux in the LWIR band with that in the MWIR band. As calculated from Planck's curve, the distribution of flux due to objects at widely varying temperatures is smaller in the LWIR band than the MWIR band when observing a scene having the same object temperature range. In other words, the LWIR infrared imaging system can image and measure ambient temperature objects with high sensitivity and resolution and at the same time extremely hot objects (i.e. >2000K). Imaging wide temperature ranges with an MWIR system would have significant challenges because when the latter is adjusted so that the detector does not saturate due to the energy from the high temperature object (by optical attenuation or short integration times), the result is poor sensitivity for imaging at background temperatures.

Figure 3: Comparison of flux in two infrared imaging systems



Ironically, the LWIR imaging system is not only suitable for high intra-scene dynamic range applications, but also uniquely suited for high contrast imaging when the amount of scene flux is quite small. As an example, consider the application of infrared imaging of cold objects at temperatures down to -100°C. These objects have very little infrared radiation. However, an MCT-based LWIR imaging system has the unique ability to image and measure these very cold objects. Figure 4 shows the detector response measured as a result of objects at temperature of about (-50) to (-95)°C. Clearly, an MCT-based LWIR system can adequately measure and distinguish the radiation from objects at temperatures down to -100ºC. In addition, it has been shown that the full object temperature range can be imaged with one detector integration time.

Figure 4: LWIR Imaging of Cold Objects



High Performance LWIR Camera Designs

One of the most important aspects of LWIR technology is not simply in the sensor/detector but equally, if not more importantly, in the camera design itself. While it is no simple feat to create a high performance thermal imager, the true key is to create an exceptional system that takes advantage of all of the performance attributes of such a high performance sensor.

This begins at the A/D circuitry. Today, it is possible to create an extremely deep dynamic range of 14 bits to best take advantage of the inherent detector dynamic range. This is a significant improvement over previous 8 and 12 bit systems.

In addition, in today's thermal imaging systems the cameras themselves include significant on-board signal processing to provide usable data directly from the camera head itself. Systems today have internal memory which allows the user to store non-uniformity (NUC) and bad pixel replacement (BPR) algorithms without the use of an external computer or separate digital processor. The user can then choose whether to capture corrected or raw data. This "one box" approach allows a smaller footprint, less cabling, and significantly less power requirements.

Also, because of innovations in DSP technology, these ultra fast cameras (>250 full frames per second) can invoke what is called "Multi Integration Time" (multi-IT mode) features. Systems today have the ability, as mentioned above, to store multiple integration time corrections internally. Certain applications (ranging from printed circuit board analysis to ballistics testing) require very wide thermal dynamic ranges, which may not be possible with a single integration time. A multi-IT mode will allow the user to cycle through integration times at the fastest rate that the camera can produce.

AN EXAMPLE: If the camera has three integration times (say 20µs, 90µs, and 200µs) to cover a wide scene temperature, the camera will cycle through integration times at full frame rates. Otherwise stated, if the camera is running at 240 frames/second, the first frame will be at the first integration time, the second frame will be at the second IT, the third will be at the third IT, the fourth will be at the first, etc. The system will effectively generate three sequences, three frames apart, each at 80 frames/second using the three integration times. There is also image processing available which will "recompose" these individual three sequences into one complete sequence making a pixel by pixel determination as to which IT should be used, further increasing the dynamic range.

Conclusion

In the age of very high-speed digital thermal imaging, there is the possibility to simultaneously capture high-speed digital video while simultaneously streaming analog video. To accomplish this, the cameras today incorporate a "video frame buffer" which allows both this possibility of simultaneous high-speed digital video and standard RS170 (or CCIR) analog output. Previously, at digital frame rates above 60 frames per second could not create an analog video output. In summary, with the innovation of much higher performance MCT infrared detectors combined with state of the art camera design and signal processing, end users are able to exploit the technology of thermal imaging in ways that were not possible before.

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