A new large-format digital mid-wave IR detector

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An indium antimonide photodetector for high-end applications is developed with a readout integrated circuit in an advanced CMOS process.

An important trend in the development of IR detector arrays is to increase the number of pixels and reduce their size. This permits increases in both the spatial resolution of the image and field of view (FOV). Alternatively, one can reduce the overall system size by maintaining a similar resolution with smaller and lighter optics, i.e., with shorter focal length and smaller optical diameter. These improved IR detector arrays are typically intended for use in high-end thermal imagers and situational awareness applications. To address current detector needs, our team developed a mega-pixel indium antimonide (InSb) detector, Hercules, which has a 1280 \times 1024 pixel array format and 15/μm pitch. \(^1, 2\)

Realizing large detector arrays with small pixel size has a number of challenges. For example, the small size of an individual InSb photodiode element must maintain high responsivity, low dark current, and low noise levels. Another challenge is the large size of the complete InSb array, which has to be uniform and manufacturable\(^1\) with few defects. To meet typical limitations on size, weight, and power, the readout integrated circuit (ROIC) has to be fabricated with advanced high-resolution CMOS technology. The ROIC reads the diode current with low noise and multiplexes the signal out to the system. Thus, the ROIC enables high capacitance values for signal-charge storage in each pixel as well as low operating voltages for reduced power consumption. High-resolution CMOS also offers high-speed digital circuitry and a high density device layout for enhanced functionality.

By passing functionality from the system to the ROIC, it is possible to reduce overall system power consumption and size while ensuring signal integrity and stability to environmental conditions. In 2002, we introduced the first digital detector, which had 640 \times 512 pixels and a 20/μm pitch.\(^3, 4\) Since then, we have developed a variety of digital detector formats, for example, the 20/μm pitch ‘Sebastian’ family with 640 \times 512, 480 \times 384,\(^5\) and 320 \times 256 pixels. Hercules maintains the same functionality as before, but in a smaller pitch (15/μm), using 0.18/μm CMOS technology.\(^1\) The digital ROIC has 2560 analog-to-digital

Figure 1. Noise equivalent temperature difference 2D map at 50% well-fill, F/4, and 77K. The color scale is in mK.

Figure 2. Deviation from linearity of the measured signal. The well-fill is varied by changing the integration time.

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converters (two for each column), which allows full-frame readout at a rate of 100Hz. Despite the array size and high-data-rate, the resultant total power consumption of the ROIC is rather low at 80mW for 60Hz and 130mW for 100Hz of full-format frame rate.

This new ROIC\(^1,2\) performs pixel readout without introducing additional noise components. Figure 1 shows a focal plane array (FPA) 2D map of the noise equivalent temperature difference (NETD) at 50% well-fill, which is a measure of electrons collected in the capacitor and a standard measure of the signal in the pixel. NETD is a measure for the sensitivity of each pixel in the array, and is defined as the ratio between the temporal noise and responsivity. The detector has a background limited performance (because of the low readout noise and dark current) that is determined by the shot noise of the arriving photons. We observed no spatial features in the temporal noise, which indicates no additional process- or readout-related noise mechanisms (see Figure 1). Figure 2 shows the readout linearity exhibited by Hercules over almost its full dynamic range. The deviation from linearity is less than 0.06% of the full dynamic range from 5–90% of capacitor well-fill. Notably, this level of performance is actually achieved at the system level, since the ROIC output signal is digital.

We took great care with the mechanical design because our detectors need to withstand harsh environmental conditions while maintaining a high level of performance. Despite its relatively large size, the Hercules FPA was integrated into a standard Dewar—based on a rugged external envelope—that supports the cold finger by struts, which are made from a stiff material with low heat conductivity. We optimized the Dewar structure and geometry for a high natural frequency and low heat load. Additionally, the cold radiation shield was designed using ray-tracing simulation to minimize stray light and optical ghosts in typical imaging scenes and environmental temperature changes.

We tested the integrated detector/cooler assembly (IDCA) in an environmental chamber. The detector was cooled down to its operational temperature of 77K and we calculated the non-uniformity correction (NUC) coefficients at ambient temperature (25°C) using a standard two-point correction procedure. We then varied the temperature in the chamber. We plotted the residual non-uniformity (RNU) against the signal capacitor well-fill (see Figure 3). We found that, when the ambient temperature was increased by as much as 20°C, the RNU degraded only slightly and in the region of the two NUC correction points. We related this minor RNU degradation to IR radiation emission from the window of the Dewar, which was in the FOV of the FPA. Stray light from other parts of the Dewar was negligible. Figure 4 shows an aerial image obtained using our Hercules IDCA from an 8km height. The image quality from the electro-optical system is superb and excellent resolution is achieved.

We also developed other 15μm pitch InSb detector arrays with advanced 0.18μm CMOS ROICs. These include the smaller Pelican-D model\(^6\), which has a format of 640 × 512 (video graphics array, VGA) and full-frame readout rate of 380Hz.

**Figure 3.** Residual non-uniformity (RNU) against well-fill at different ambient temperatures using the same non-uniformity correction coefficients that were determined at an ambient temperature of 25°C.

**Figure 4.** An image obtained using the Hercules integrated detector cooler assembly from an 8km height. Courtesy of VISIONMAP LTD.

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Additionally, the SNIR VGA format detector includes asynchronous laser pulse detection and the 2D laser range finder modes of operation.7

In summary, we developed a large-format InSb photodetector with a ROIC fabricated using advanced high-resolution CMOS technology. In future work, we will continue to pursue smaller pixel, large arrays with increased functionality on chip.

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References

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