PROCEEDINGS OF SPIE

Infrared Technology and Applications XXXVI

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Editors

5–9 April 2010
Orlando, Florida, United States

Sponsored and Published by
SPIE

Part One of Two Parts

Volume 7660

Proceedings of SPIE, 0277-786X, v. 7660

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

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Author(s), "Title of Paper," in *Infrared Technology and Applications XXXVI*, edited by Bjørn F. Andresen, Gabor F. Fulop, Paul R. Norton, Proceedings of SPIE Vol. 7660 (SPIE, Bellingham, WA, 2010) Article CID Number.

ISSN 0277-786X
ISBN 9780819481245

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

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Introduction

The Thirty-Sixth conference on Infrared Technology and Applications was held the week of April 5-9, 2010 at the Orlando World Center Marriott Resort and Convention Center in Orlando, Florida. The agenda was divided into 19 sessions:

1. Infrared in the service of the Navy
2. Systems for high situational awareness
3. Target acquisition
4. Passive imaging in SWIR and below
5. Uncooled FPAs and Applications I
6. Uncooled FPAs and Applications II
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10. IR Optics
11. Hyper- and multispectral imaging
12. Cryocoolers for IR Focal Plane Arrays
13. HOT—High Operating Temperature FPAs
14. Keynote—The critical role of MOVPE technology in thermal imaging capability
15. Next generation HgCdTe detectors
16. Active imaging
17. QWIP, QCD, QDIP, and Dwell FPAs
18. Signal processing
19. Selected Application Presentations

In addition, there were twenty-five poster papers presented for discussion on Thursday evening. Highlights of five topical areas are summarized below:

- Applications
- Optics
- Uncooled thermal detectors
- Photon detectors
- Cryocoolers

Applications

Applications can roughly be divided into three types:

1. Situational awareness systems
2. Soldier systems
3. Hyper- and multi-spectral imaging systems

Target search systems covering 360° in azimuth and, typically, 40° to 60° in elevation were discussed in two sessions. One session reported on naval systems while the other was concerned with systems mounted on army platforms. All of the presented Infrared Search and Track, IRST, systems employ two-dimensional FPAs in order to increase the signal integration time and achieve longer range performance. One group presented a system using continuous panoramic scan and the TDI technique, while another combined the horizontal scan with a de-rotator in order obtain a scan-stop-and-stare action. Wide panoramic search without the use of a scanning head was demonstrated by using various techniques such as optical multiplexing; a 2048 × 2048 pixel FPA combined with a catadioptric omnidirectional optical system; and a simple panoramic lens whose highly distorted image may be corrected by a computer. The distributed aperture system, DAS, which employs a number of thermal imagers around the platform, was also discussed.

Detection of missiles and aircraft with a low false alarm rate at long ranges requires a high spatial resolution (small IFOV) and a high update rate. These requirements, combined with need for an elevation coverage of several tens of degrees, call for a large FPA. Lacking these FPAs, all the presenters of the various IRST system designs chose an IFOV which by far exceeded the rule-of-the-thumb IFOV of 100 µrad. Among the solutions considered in order to retain good discrimination against false targets were the addition of an active sensor (radar or laser), dual waveband, and man-in-the-loop.

Several papers were devoted to "IR for the Soldier" systems. Two night-sight modules for mounting in front of a rifle's day-sight were presented. Both modules employed uncooled microbolometers.

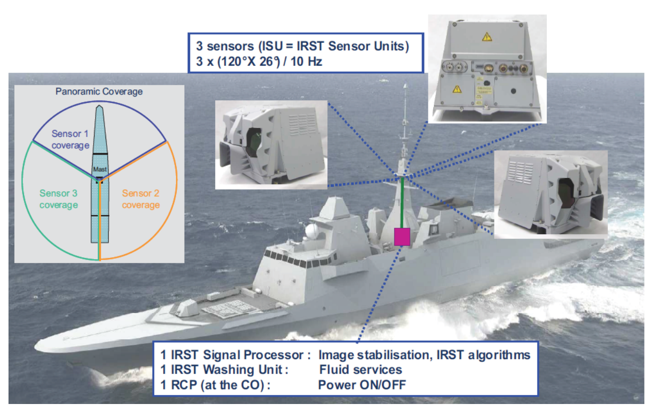

Fig. 1 Thales Optronique's Artemis IRST architecture

Fig. 2 Carl Zeiss Optronics' IRV 900 mounted on an HK 417 rifle in front of a 4×30 day-sight aiming optics.

Sensor systems operating in the ultra-violet and MWIR spectral regions have traditionally been used for detection of gun flashes, detonations and missile launches. One paper reviewed the relative performance of gunflash sensor technologies and concluded that SWIR technology is optimal for these systems. A trade-off analysis showed the InGaAs:InP to be the optimal detector. Temporal discrimination against background sun-clutter interference on a clear cloudless day was hinted at but not demonstrated.

The presented hyper- and multi-spectral imagers were using widely different techniques and technologies. The preferred concept depends on the specific application.

The concept of a Fourier-transform micro-spectrometer on chip, developed for very fast acquisition of spectral signatures, was discussed. The spectrometer is made by grinding the HgCdTe detector's CdZnTe substrate to the shape of a wedge. With backside irradiation the internal reflections occurring in the wedge will result in a Fizeau interferometer with low reflectivity mirrors.

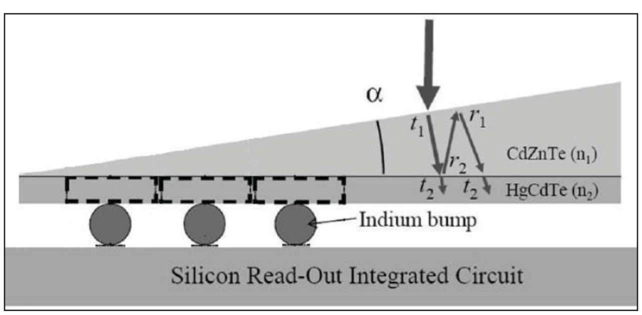

Fig. 3 CEA, LETI, MINATEC's on-chip FTIR-FPA based on HgCdTe detector technology.

A Fourier Spectrometer, based on a Michelson Interferometer, for stand-off detection and quantification of chemicals was described. It operates in the VLWIR and utilizes a linear detector array and differential acquisition in order subtract the non-contaminated background spectrum. The noise properties of a corner-cube Michelson interferometer LWIR hyperspectral imager based on an uncooled a-Si microbolometer FPA were also discussed.

By incorporating quantum dots in quantum wells DWELL QDIPs can be designed to exhibit a spectral response that can be tuned across a wide wavelength range by varying the bias voltage. A single QDIP combined with an algorithmic spectrometer technique for multi-spectral or hyper-spectral imaging was outlined.

A quantum dot photodiode (QDP) technology, which uses a unique low-cost nanotechnology-enabled photodetector, was discussed. This technology is capable of efficiently detecting light with sensitivity spanning the 250 – 1800 nm spectral region. These devices show response times less than 10 µsec, making them suitable for high speed imaging.

A miniature snapshot multispectral imager that operates in the short wavelength infrared region (SWIR) was presented. The imager uses a 4×4 Fabry-Perot filter array operating from 1487 to 1769 nm with a spectral bandpass of approximately 10 nm. The design of the filters is based on use of a MEMS shadow mask technique to fabricate a Fabry-Perot etalon with multilayer dielectric mirrors.

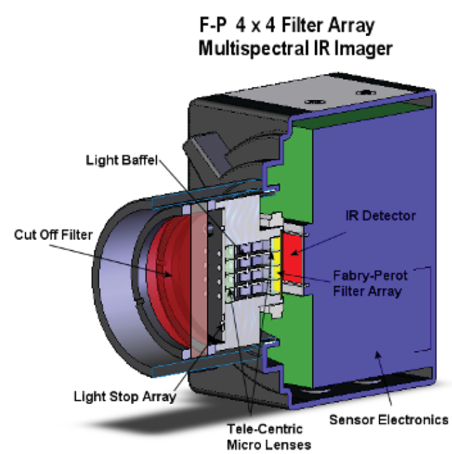

Fig. 4 U.S. Army Research Laboratory's snapshot multispectral imager. A 4×4 filter array is installed in front of the SWIR FPA.

Optics

Advanced infrared systems require multiband or hyperspectral operation. Thermal imagers of generation 3 and above will operate in two or all of the three bands SWIR, MWIR and LWIR. Good refractive optical materials which cover all three bands hardly exist and in last year's conference reflective optics was discussed as a possible solution to this three-band problem. Using conventional design, these optical systems become large. An alternative approach to infrared optics was outlined in the present conference. Concentric, aspheric reflective surfaces were used in this novel design to fold the optical path and achieve, typically, a four-fold reduction of the lens' form factor in the axial dimension while retaining high radiation collection efficiency. A stacked multiple-band compact imaging system answering the requirements of next-generation thermal imagers now becomes a reality.

Two papers presented techniques for coating of aspheric surfaces. Among the challenges discussed were how to obtain uniform performance over a wide range of look angles, good mechanical and optical performance across a temperature range of ambient to 1000 °C, and cost effective production. Some of these techniques are expected to be applicable to coating of surfaces in the unconventional optical systems referred to above.

Compactness is a main requirement for most security and defense related systems. Two papers presented wide field of view infrared optics integrated into the detector dewar. Apart from achieving compactness, this optics will not suffer defocusing due to ambient temperature drifts nor contribute noise due to emissions from the optics. The cooled optics also reduces significantly the need for periodic non-uniformity corrections. Actuators which can be compatible with the cooled dewar were reported on. These may be used in the design of an integrated zoom.

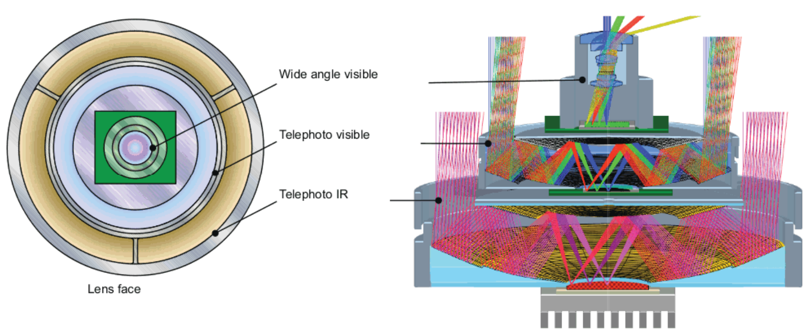

Fig. 5 Distant Focus Corporation's coaxial arrangement of folded LWIR and visible telephoto optics together with wide field-of-view visible optical systems.

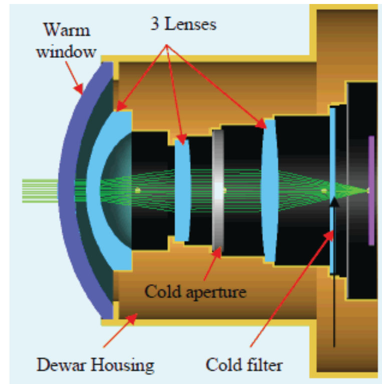

Fig. 6 SCD Semiconductor Devices' optics inside DDCA

For several years some signal processing designs have been inspired by invertebrate vision. One paper discussed a multichannel optical design inspired by the eyes of an insect called Xenos Peckii. The system is composed of multiple telescopes – each with a microprism in front of its entrance pupil.

Among other new optical techniques that were presented was the use of surface plasmon engineering tools which concentrate light power without regard for limits set by diffraction. It was claimed that zero focal length super-lenses may allow for use of smaller detector areas, having less noise, without an accompanying decrease in signal power. Another development that was discussed was the DSF (Dynamic Sunlight Filter) which increases the dynamic range of an infrared system by selectively and reversibly decreasing the high intensity radiation due to sun, fires etc.

Uncooled thermal detectors

Presentations at this conference underlined the fact that uncooled infrared focal plane array technology is reaching a new level of maturity. The two predominant technologies—vanadium oxide (VO_x) microbolometers and amorphous silicon microbolometers—are being driven to new levels of performance.

All of the leading microbolometers suppliers have developed 640 × 480 FPAs with 17 µm pixels. Some have also developed 1024 × 768 arrays and are working on even larger ones with sub-17 µm pixels.

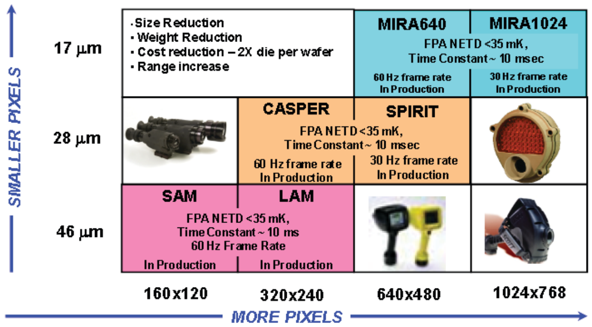

Fig. 7 BAE Systems microbolometer roadmap

Some uncooled FPA module suppliers are using outside foundries for production of the basic FPA chips and are investing in sophisticated packaging techniques in order to lower the cost of their products.

Recent new developments include a 640 × 480 (25 µm pixels) VO_x microbolometer made by a German research institute and a 640 × 480 (25 µm pixels) SOI (silicon-on-insulator) microbolometer by a Japanese company.

The use of amorphous SiGe instead of α-Si is also being investigated by a number of groups. One group concluded that, although these films have a number of advantages, they are not expected to have higher signal-to-noise because the presence of Ge results in higher 1/f noise.

The development of novel uncooled detectors is also continuing. Some of the approaches reported on in this conference include a photo-mechanical imager (an array of bi-material microcantilevers that are read out optically) which is capable of 1000 frames per second in the MWIR; a microbolometer based on single-crystal Si/SiGe quantum wells which is expected to have a higher TCR and lower 1/f noise than conventional microbolometers; an active pyroelectric array; and the use of nickel oxide films in microbolometers.

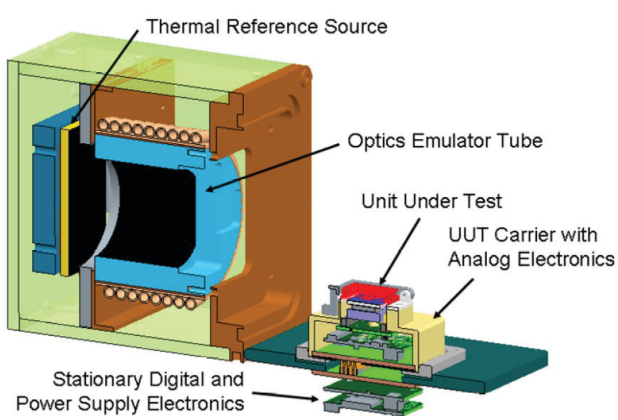

Fig. 8 Raytheon's Micro-environment for rapid temperature calibration of microbolometers.

There were also reports on research into the optical properties of antenna-coupled VO_x films, with the objective to enhance infrared absorption in small pixel microbolometers.

Photon detectors

Photon detector presentations reported good progress across the spectrum.

Beginning with the short wave infrared (SWIR), InGaAs is the leading material for passive imaging. The dark current for these detectors has been gradually going down, while the readout noise is also being reduced. An image from an InGaAs array is shown in Fig. 9.

Alternative SWIR technologies—HgCdTe, Ge, SiGe, and black Si—also reported progress in developing SWIR capabilities.

Type II superlattice FPAs have demonstrated excellent progress in recent years. They are already in production for a dual-color MWIR threat-warning sensor in Germany. The appeal of these artificial narrow bandgap materials is that they can potentially have longer lifetimes than HgCdTe material. The rate of progress has been summarized in Fig. 10 where the dark current of

Fig. 9 A SWIR image taken with a 640 × 480 InGaAs array under minimal street-lighting conditions.

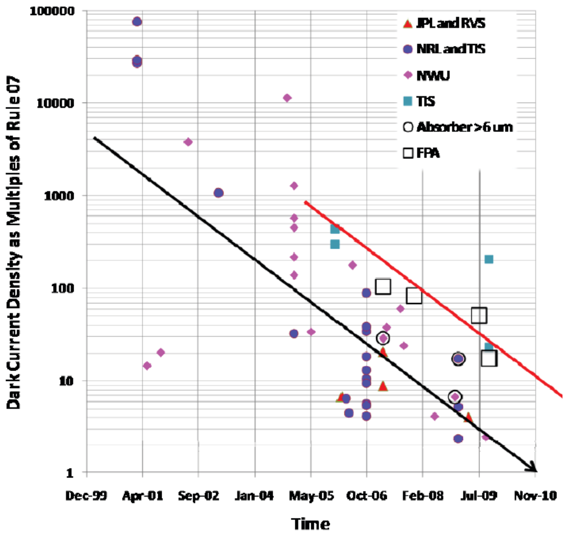

Fig. 10 Dark current density as a multiple of Rule 07 vs. time. The long black line is drawn as an eye aid to show the trend of dark current reduction along time for single-element detector, and the shorter red line helps to show the trend for FPAs.

Type II materials is compared with that of HgCdTe as calculated from Rule 7. The suggested trend line forecasts that by November 2013, the dark current of Type II LWIR superlattice FPAs will be reduced to that of HgCdTe, and that by July 2016 the dark current will be an order of magnitude less.

A notable change in traditional FPA development and procurement is planned along with the maturation of the Type II superlattice technology; namely, a transition from vertically-integrated suppliers to one where materials-technology expertise is resident in III-V commercial growth foundries rather than at FPA suppliers.

There are several remaining challenges to bring Type II superlattice technology into a competitive position with the more mature HgCdTe. First, the lifetime of Type II superlatice materials remains more than an order of magnitude shorter than that of HgCdTe—the result of which is that the dark current is significantly higher—see Fig. 10 above. At present, the cause of the short lifetime has not be identified.

FPA builders have responded to this challenge in two ways. One is to dope the absorber layer more heavily to minimize the minority carrier concentration. The second is to incorporate barriers by putting the junction in the wider bandgap region of a heterojunction—one result of which is to require ~100 mV reverse bias before photocurrent can be collected. These temporary fixes have allowed progress to continue, but ultimately the fundamental issues must be addressed.

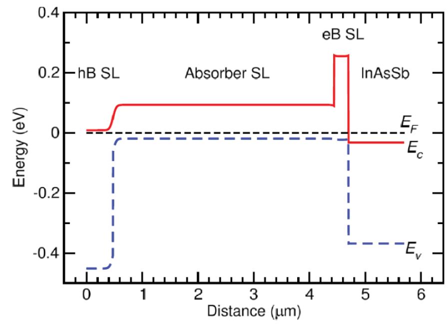

Fig. 11 The energy band diagram of the CBIRD structure showing the conduction and valence band edges and the Fermi level. The substrate is toward the right. The electron barrier (eB) appears in the conduction band at the right and the hole barrier (hB) in the valence band on the left. The thickness of the absorber region in this illustration is 600 periods. Reverse bias is defined as a negative voltage on the InAsSb layer.

Barriers that block majority carriers, analogous to those used in nBn detectors have also been employed in the Type II materials. Figure 11 illustrates one of these, the CBIRD structure.

Finally, the science of passivation remains to be established for the Type II superlattice detectors, in particular those employing InAs.

A half-day session was devoted to high-operating temperature (HOT) detectors. The main technologies in this arena include HgCdTe and nBn structures, with secondary contenders using split-off band detectors, carbon nanotubes, and PbSe. In this session, DRS showed HgCdTe results with low NEΔT for an MWIR 640 × 480 array having 12 μm pixels at 160 K as illustrated in Fig. 12.

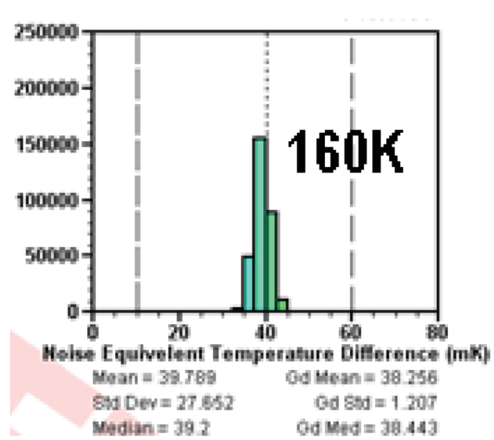

Fig. 12 Histogram of DRS HgCdTe NEΔT at f/3 of a MWIR 640 × 480 12 μm pitch FPA at 160 K.

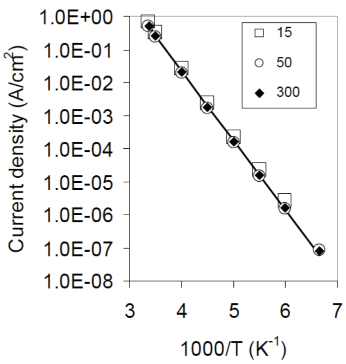

Fig. 13 Arrhenius plot of the dark current density of an nBn device at -0.2 V bias vs. reciprocal temperature for mesa dimensions of 15, 30, and 300 µm. The solid line is an exponential fit to the data points for the 300 µm device.

Progress with nBn detectors is extremely active. The barrier in this structure is used to block majority carrier current, eliminating g-r currents and allowing the diffusion current to dominate to much lower temperatures, as illustrated in Fig. 13. However, at higher temperatures where g-r currents are not dominant, nBn structures will not provide an advantage over diode structures.

The conference keynote session, presented by Vic Leverett of Finmeccanica U.K. discussed the important role of MOVPE technology in advanced HgCdTe detector technology developments. Growth on large GaAs substrates, including arrays of dual-band and avalanche photodiodes has been successfully demonstrated with this technique. Overall the cost per pixel has been reduced—doubling the number of pixels that can be built for the same cost every five years.

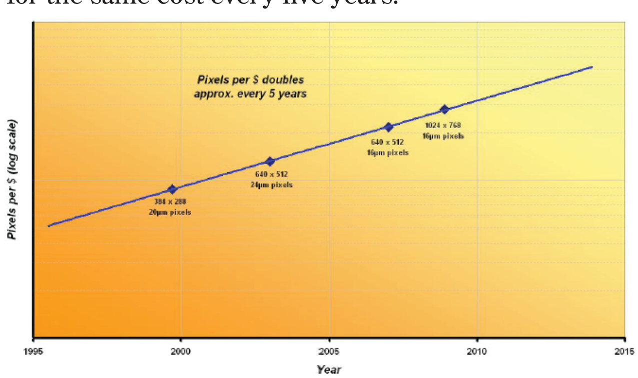

Fig. 14 Trend of pixels/$ for HgCdTe FPAs grown by MOVPE.

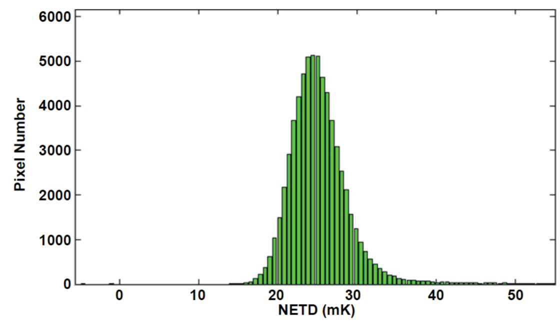

Fig. 15 A histogram of NEΔT at 55 K for a 14.7 µm cutoff detector at halfwell condition showing a mean NEΔT of 23.9±3.1 mK.

Advances in HgCdTe detectors were reported, including the reduction of pixel size to 12 µm for some MWIR arrays, plans for further pixel reduction to 10 µm by 2012, the development of arrays that can operate in passive or active mode, fast frame-rate arrays for FTIR applications, improved CdZnTe substrate quality, and improved performance for LWIR and VLWIR arrays. Fig. 15 shows an example of the NEΔT for an array with a cutoff of 14.7 µm at 55 K—relevant to space sensors for important weather forecasting applications

Active imaging technology was likewise able to show off significant progress at the conference. Active imaging is based on the avalanche process in materials such as HgCdTe, InGaAs, Si, Ge, and SiGe alloys. These materials feature photo-signal gain via a carrier-multiplication process that is a function of bias across the device junction. Progress was reported in developing effective readout circuits that can operate such arrays in both

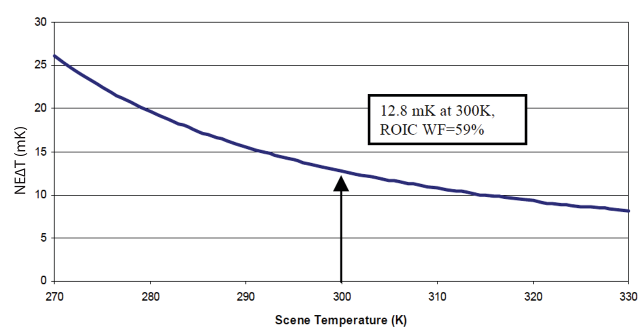

Fig. 16 NEΔT as a function of scene temperature for a HgCdTe MWIR array operating in the 3.4 - 4.15 µm band with f/4 optics. Device gain is used to prevent readout noise from dominating at low flux levels.

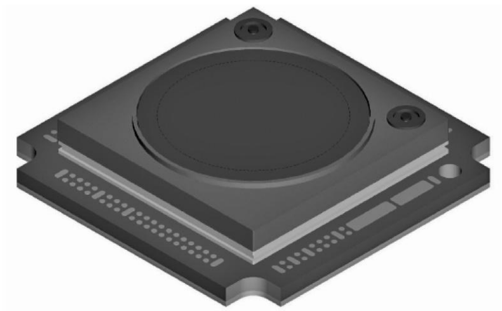

Fig. 17 Compact room-temperature avalanche-photodiode package containing a 256 × 256 HgCdTe array with a readout that can process multiple signal returns from a pulsed laser.

passive, non-avalanche conditions, and in active mode where the internal gain is used to overcome dominant amplifier noise under low flux sensing conditions. Fig. 16 shows how this allows for very low NEΔT for a passive MWIR sensor operating in the 3.4 - 4.15 µm band at f/4.

Other active imaging work is being carried out to implement 2D and 3D laser radar (LADAR) capabilities. A compact 3D sensor with M = 300 was described that provides essentially noiseless gain at room temperature combined with a readout that can process multiple pulse return signals. The sensor package containing a 256 × 256 array with 60 µm pixels is shown in Fig. 17.

GeSi APDs were also reported having gain-bandwidth products in the range of 350 - 860 GHz at 1.31 µm. Fig. 18 shows the device cross-section. The devices are deployed in a waveguide structure.

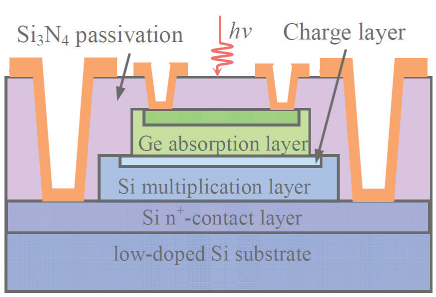

Fig. 18 SiGe APD pixel from UCSB/Intel with very high gain-bandwidth products at 1.31 µm.

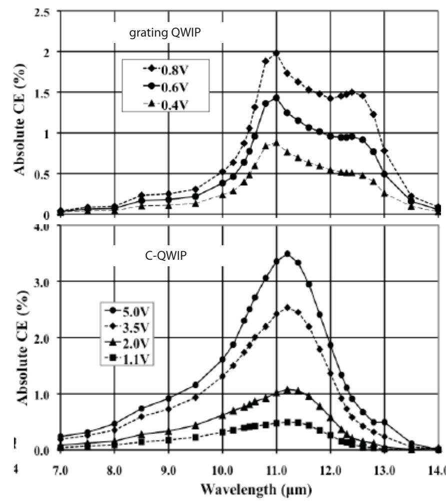

Fig. 19 The absolute collection efficiency (quantum effeciency × gain) for two QWIP technologies—grating QWIP and C-QWIP—to be used on the Landsat continuity mission.

QWIP and other quantum-structured technologies reported new milestones in development. The first QWIP devices operating at 43 K are slated to go into orbit on a NASA Landsat Continuity mission. Production of QWIP arrays were summarized and quantum cascade detectors for a broad range of the infrared spectrum were introduced.

Signal processing papers included a description of the Jazz silicon foundry features for readout production. Additionally, Fourier processing on-chip was described to enhance signal-to-noise ratio and an update on negative-luminescence in HgCdTe as a calibration reference source.

Cryocoolers

Fine progress was reported on the development of compact split Stirling linear cryogenic coolers. Redesign resulted in elimination of the advantages that traditionally have been associated with rotary integral coolers – smaller size, lower weight and lower power consumption. Among the applications listed for these coolers are portable hand-held cameras, thermal weapon sights, ground fixed and vehicle mounted surveillance cameras and gyro-stabilized imagers.

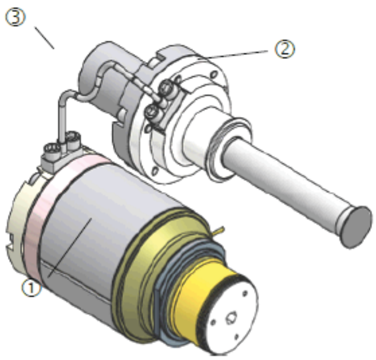

Fig. 20 Ricor's K527 split Stirling linear cryogenic cooler

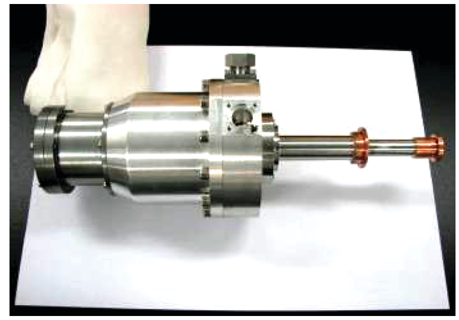

Fig. 21 SITP's 35K two-stage Stirling cryocooler

One paper discussed the adaption and application of integral rotary cryogenic coolers for airborne infrared missile warning systems where the ambient temperature inside the system may reach up to 110 °C with random vibration above 10 g rms and catapulting and landing shocks of up to 300 g. Other cryocooler characteristics which were demonstrated were digital drive electronics, and endurance and reliability. It was shown that the very high acoustic power density achieved at higher pressures and higher frequencies in pulse-tube cryocoolers lead to very short cooldown times and very compact devices.

Five papers presented by researchers from Shanghai Institute of Technical Physics, SITP, showed fine progress in the development of both single- and double-stage Stirling cryocoolers. The cooling temperature covers 30 K to 100 K. The main presented applications of their Stirling and pulse tube cryocoolers were space-related.

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