

INFRARED DETECTORS OVERVIEW IN THE SHORT WAVE INFRARED TO FAR INFRARED FOR CLARREO MISSION

M. Nurul Abedin and Martin G. Mlynczak

NASA Langley Research Center, Hampton, VA 23681

Tamer F. Refaat, Old Dominion University, Norfolk, VA 23524

ABSTRACT

There exists a considerable interest in the broadband detectors for CLARREO Mission, which can be used to detect CO₂, O₃, H₂O, CH₄, and other gases. Detection of these species is critical for understanding the Earth's atmosphere, atmospheric chemistry, and systemic force driving climatic changes. Discussions are focused on current and the most recent detectors developed in SWIR-to-Far infrared range for CLARREO space-based instrument to measure the above-mentioned species. These detector components will make instruments designed for these critical detections more efficient while reducing complexity and associated electronics and weight. We will review the on-going detector technology efforts in the SWIR to Far-IR regions at different organizations in this study.

Keywords: Broadband, detectors, short wave, mid wave, long wave, very long wave, far-infrared, Pyroelectric, Si bolometer, CLARREO.

I. INTRODUCTION

Climate Absolute Radiance and Refractivity Observatory (CLARREO) is one of the 15 missions within National Research Council's (NRC) decadal survey, which was recommended for high priority flight missions and activities to support national needs for research and monitoring of the dynamic Earth system during the next decade¹. This CLARREO mission consists of three instruments and these are i) Absolute spectrally resolved infrared radiance, ii) Incident solar and spectrally resolved reflected irradiance, and iii) Global Navigation Satellite System Radio Occultation (GNSS-RO) for absolute calibration for operational sounders. The Absolute spectrally resolved infrared radiance within the CLARREO mission is the broadband infrared detection instrument for Earth Science applications for studying atmospheric spectra of CO₂, O₃, H₂O, CH₄ and other gases from space is a major concern for precise measurements. Therefore, there is a critical need for detector, which can detect broadband infrared radiation in the 5- to 50- μ m wavelength range. We will discuss the existing and most recent developing detectors in this paper that can be possible potential candidates within the above-mentioned wavelength range.

Today, there is not any single detector available with high sensitivity that is suitable to detect this broadband radiation. The main focus in this paper is to study commercially available broadband detector for applications to atmospheric remote sensing. Using current technologies, each wavelength band requires a separate detector with appropriate electronics, optics, cooling, and mounting hardware and these components increase the size of detection systems. The broadband detector eliminates the requirements of multiple detectors, optical, electrical, and cooling components in a detection system, which potentially results in a reduction of power, cooling, weight, size, and cost of the overall system.

Many different device structures, such as InSb/HgCdTe sandwich, HgCdTe, GaAs/AlGaAs quantum well photodetectors, strained layer InAs/GaInSb superlattices (SLS's), Schottky barrier on silicon, SiGe heterojunctions, thermopiles, pyroelectric detectors, silicon bolometers, and high temperature superconductors are used for the detection of short infrared-to-far infrared radiation. InSb/HgCdTe sandwich detector, HgCdTe and GaAs/AlGaAs quantum well infrared photoconductors (QWIPs) present mid-infrared capability in the 3- to 15- μm wavelength range. HgCdTe is based on II-VI and QWIP is based on the well-developed III-V material systems, which have some advantages and disadvantages. HgCdTe Focal Plane Arrays (FPAs) have higher operating temperature, higher quantum efficiency, but lower yield and higher cost. On the other hand, QWIPs are easier to fabricate with high operability, good uniformity, high yield, and lower cost, but have discrete narrow bands, lower quantum efficiency and lower operating temperature. Dual-band InSb/HgCdTe sandwich detectors have been used in Portable Atmospheric Research Interferometric Spectrometer for the Infrared (PARIS-IR) as a ground-based and balloon-borne instrument for atmospheric remote sensing². Three narrow-band InSb and HgCdTe focal plane arrays (FPAs) have been used in Infrared Atmospheric Sounding Interferometer (IASI)³, HgCdTe FPAs have been used in Atmospheric Infrared Sounder (AIRS)⁴ and Cross-track Infrared Sounder (CrIS)⁵ applications to allow broadband detection (3 - to 15-micron) with high quantum efficiency (>60%) and high detectivity (>10¹⁰ cm-sqrt (Hz)/W). Four-band FPAs based on QWIPs have been developed by JPL group in the 3-to-15 μm region⁶. There is no quantum detector technology exist in the spectral range from short wave-to-far infrared (5- to 50- μm), a region that has important potential benefits to NASA Earth Science applications from space.

Pyroelectric detectors, thermopiles, and silicon bolometers have the capability for the CLARREO infrared instrument in the 5- to 50- μm wavelength range. Si bolometer has a great advantage to acquire this wavelength range radiation with high sensitivity at liquid helium temperature (4.2K), but this temperature is not suitable for long-term applications in space. On the other hand, thermopiles and pyroelectric detectors can operate at ambient temperature, but thermopile is slower than pyroelectric detector. Therefore, a pyroelectric detector is a potential candidate for far infrared region with comparatively high-speed detection capability with respect to thermopile. Far-Infrared Spectroscopy of the Troposphere (FIRST) and Radiation Explorer in the Far Infrared (REFIR) instruments have been designed and developed using silicon bolometers⁷ and deuterated L-alanine doped triglycine sulphate (DLATGS) pyroelectric detectors⁸, respectively, by providing measurements of the species with very high vertical resolution. In addition, extended wavelength Si Blocked Impurity Band (BIB) detector and Antenna Coupled Terahertz Detector (ACTD) are the potential candidates for applications to future atmospheric remote sensing and these detectors are under development⁹. We will discuss the state-of-the-art short wave to far infrared detectors, such as InSb/HgCdTe sandwich, PC/PV HgCdTe, GaAs/AlGaAs (QWIP), Si Bolometer, pyroelectric detector, Si BIB and ACTD detectors in the following sections.

II. INFRARED DETECTOR TECHNOLOGIES

In this section, we focus on current and the most recently developed detectors in addition to emphasizing in SWIR-to-Far infrared broadband detectors for space-based instruments to measure CO₂, CH₄, water vapor and greenhouse gases¹⁰. This novel detector component will make instruments designed for these critical measurements more efficient while reducing

complexity and associated electronics and weight. We will discuss the commercially available detectors, in addition to on-going detector technology development efforts in the SWIR to Far-IR regions at Teledyne Judson Technologies, BAE Systems, Teledyne Technologies (previously, Rockwell Scientific Company), SELEX GALILEO, Infrared Laboratories Inc., DRS Sensors and Targeting Systems, and Raytheon Vision Systems.

A. Mid-IR Detectors

InSb/HgCdTe sandwich detector, photoconductive (PC)/photovoltaic (PV) HgCdTe and QWIPs present mid-infrared capability in the 3 – 15 μm wavelength range. InSb/HgCdTe dual band detector has been fabricated at Teledyne Judson Technologies with high detectivity ($>10^{10}$ cm-sqrt (Hz)/W)¹¹. Broadband photoconductive and photovoltaic detectors based on HgCdTe material systems have been demonstrated by BAE Systems for application to AIRS in the 3.7- to 15.4- μm ⁴ and AIRS Light PV HgCdTe detector has extended the cutoff wavelength up to 16- μm under NASA Instrument Incubator Program (IIP)¹². Conversely, Teledyne Technologies developed the PV HgCdTe detectors for the CrIS mission applications in the 3.5- to 15.4- μm region¹³.

A.1 InSb/HgCdTe Sandwich Detector

Existing technology, such as InSb/MCT sandwich detectors, sensitive in the broadband range with two different bands covering the 1- μm to 16.6- μm wavelength range is considered for mid-infrared region. To achieve these sandwich structures, Indium Antimonide (InSb) and Mercury Cadmium Telluride (HgCdTe) alloy-based materials are vertically mounted. Radiation of the appropriate wavelengths of interest is absorbed in the first detector (1.0 – 5.5 μm) in this “sandwich”, while longer wavelengths are not absorbed. Longer wavelengths are passed into the second detector and this second set of wavelengths is absorbed in the second detector (6.0 – 16.6 μm). The dual band detector focal planes are spaced within 0.5 mm and their centers are aligned to within 0.15 mm during mechanical assembly¹¹. The dual band InSb/HgCdTe sandwich detector operates at 77°K and is mounted in the standard metal dewar with a ZnSe window. The InSb/HgCdTe sandwich device structure is shown in Figure 1. This dual band detector needs separate preamplifiers to acquire output signals from each band.

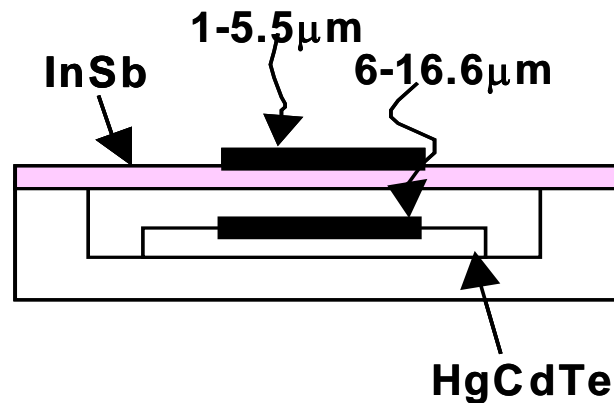


Figure 1. Schematic of InSb/HgCdTe sandwich broadband Mid IR detector

A.2 PC/PV HgCdTe

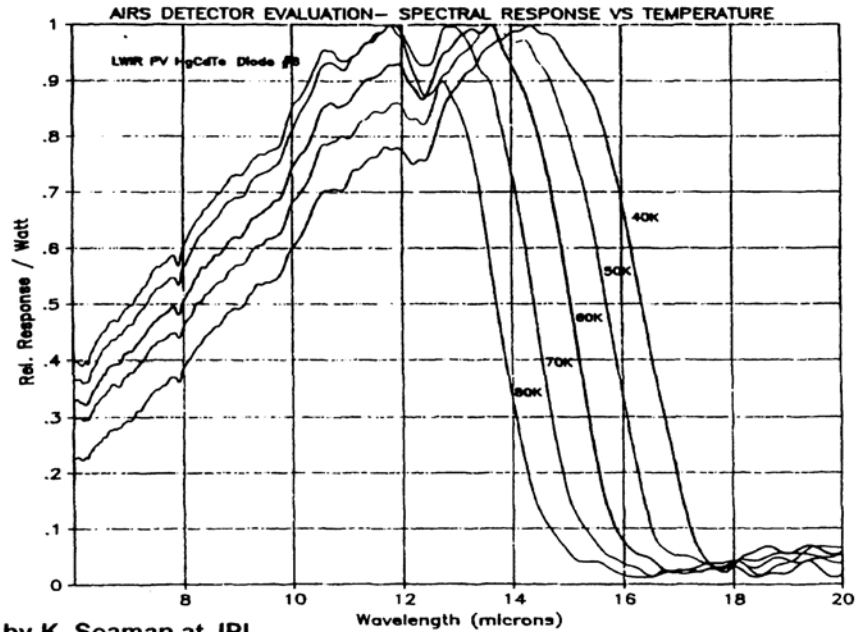
Considerable advancement has been made in broadband HgCdTe detectors employing Liquid Phase Epitaxy (LPE) and Molecular Beam Epitaxy (MBE) for the growth of a variety of devices by research groups at BAE Systems (previously, Lockheed Martin), Hughes Research Laboratory, Teledyne Technologies (previously, Rockwell Scientific Company), DRS Technologies, and CEA/LETI (France). Photovoltaic HgCdTe detector is considered as an alternative to photoconductive HgCdTe (InSb/HgCdTe sandwich structures) to overcome the linearity problem present in photoconductive detectors. The alternative PV detectors are based on the integration of SWIR, MWIR, and LWIR or VLWIR HgCdTe detectors to obtain the wavelengths of interest in the 3.0- to 16.0- μm . BAE Systems, CEA/LETI and Teledyne Technologies developed these detectors using LPE and MBE techniques, respectively, for AIRS/AIRS Light, IASI, and CrIS Programs. Here, we will discuss only the performance characteristics of AIRS/AIRS Light and CrIS detectors.

The AIRS instrument utilized PV HgCdTe detectors to cover the 3.7 - 13.8 μm spectral region, with the longest cutoff wavelength at 15.0 μm . Two linear arrays of PC HgCdTe detectors covered the 13.7 - 15.4 μm band and all arrays operated at a temperature of 60 K. BAE has since extended the useful cutoff wavelength for PV HgCdTe from the 11 - 12 μm region out to beyond 17 μm , and has developed LPE film growth and array processing to the point that high quantum efficiencies (>70%) and high D^* values (in the $3\text{-}5 \times 10^{11}$ $\text{cm}\cdot\text{sqrt}(\text{Hz})/\text{W}$ range) can be achieved at 60 K¹⁴.

Figure 2 shows the relative spectral response (response/watt) vs wavelength data for a photodiode at different temperatures. The spectral response characteristics of the backside-illuminated VLWIR P-on-n LPE PV HgCdTe photodiodes are well behaved. The increase of the cutoff wavelength with decreasing temperature is well illustrated in Figure 2 for an HgCdTe photodiode with a cutoff wavelength of 15.04 micron at 60 K. These data were taken by K. Seaman at the Jet Propulsion Laboratory (AIRS Array LD057FB λ_{co} (60 K) = 15.04 μm). The relative response per watt curves show the expected increase in cutoff wavelength as temperature is lowered from 80 K to 40 K¹⁴.

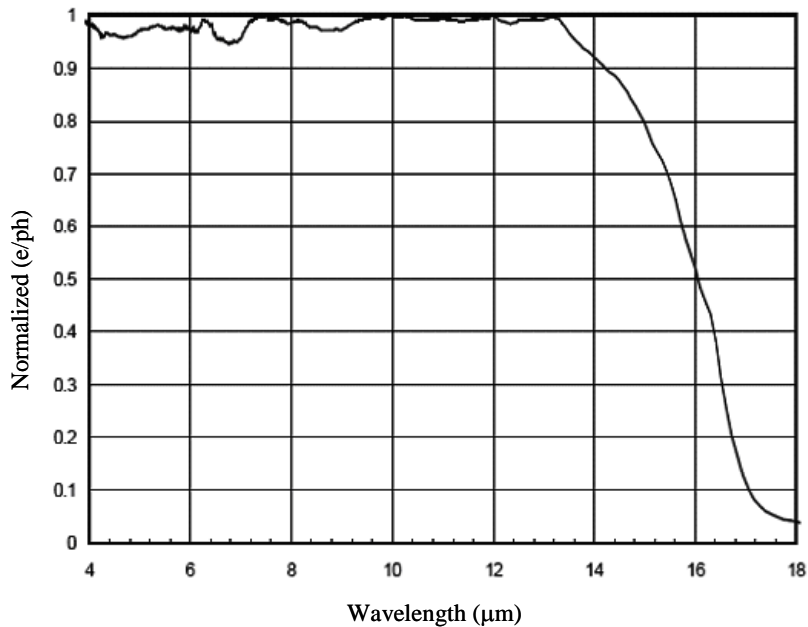
Figure 3 shows the normalized quantum efficiency (e-/ph) vs wavelength of one of the AIRS Light photodiode with a cutoff wavelength around 16.37 μm at 60 K and high response in the 13.4 - 15.4 μm region¹². BAE Systems has demonstrated the extension of photovoltaic HgCdTe detectors from 13.4 μm (for AIRS) to 15.4 μm (for AIRS-Light) under NASA IIP program.

Previously, Teledyne Technologies fabricated state-of-the-art large area photovoltaic HgCdTe detectors grown by Molecular Beam Epitaxy and demonstrated their performance characteristics for the CrIS instrument¹³. Figure 4 shows quantum efficiency vs wavelength for the three spectrally separate SWIR, MWIR and LWIR detectors and flat spectral QE was determined in each spectral band. All devices have the same area, around 1 mm in diameter, and operating at 98K for SWIR with cutoff around 5 μm (device # 5_2) and MWIR with cutoff around 9 μm (device # 10_2) and at 81K for LWIR with cutoff around 15 μm (device # 7_5). Quantum efficiency vs wavelength was determined on all of the detectors under backside-illuminated condition. Observed dips at near 4.2 μm and near 5.5 to 6.2 μm wavelengths are due to atmospheric CO₂ absorption bands and are a measurement system artifact¹³.



Data taken by K. Seaman at JPL
 AIRS Array LD057FB
 $\lambda_{co}(60\text{ K}) = 15.04\ \mu\text{m}$

Figure 2. Relative spectral response vs wavelength (response/per watt) for an LPE P-on-n HgCdTe photodiode for temperatures between 40K and 80 K¹⁴.



Cutoff = 16.37 μm , Meets M12 Goal of 16.17 - 16.94 μm

Figure 3. Normalized quantum efficiency (e-/ph) response with M12 band cutoff¹².

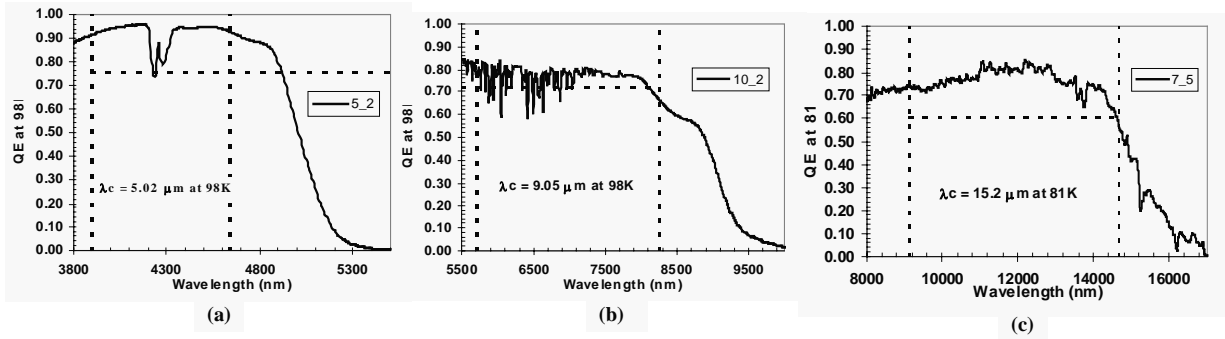


Figure 4. Quantum efficiency plots for (a) SWIR at 98K for device # 5_2, (b) MWIR at 98K for device # 10_2, and (c) LWIR at 81K for device # 7_5 on 1mm diameter MBE p-on-n HgCdTe PV-detectors. Dashed lines are the required QE specification of the CrIS program¹³. (Provided by Dr. D'Souza, DRS Technologies).

The performance specifications of these InSb/HgCdTe sandwich detectors¹¹, AIRS PV-PC HgCdTe⁴, AIRS Light PV HgCdTe¹² and CrIS PV HgCdTe¹⁵ detectors are tabulated in Table 1.

Table 1. Teledyne Judson InSb/MCT Sandwich Detectors, PV/PC AIRS Detectors, and PV CrIS Detectors:

Detector	InSb/MCT Sandwich (J15D16InSb-DM1-S02M-60)	PV-PC AIRS (PV AIRS Light) Detectors	PV CrIS Detectors
Parameters			
Detector Type	Photovoltaic/Photoconductive InSb/HgCdTe	Photovoltaic HgCdTe: AIRS/AIRS Light	Photovoltaic HgCdTe :
Spectral Range	1 – 5.5 μm /6 – 16 μm	(3.74 – 13.75 μm) / (4.0 – 16.4 μm)	3.5 – 16 μm
Size	2.0 mm dia. /2.0 mm x 2.0 mm	50 μm x 100 μm / (400 μm (dia.), 200 μm (dia), etc.)	1000 μm diameter for SWIR, MWIR, & LWIR
Detectivity (D*)	Peak D* @ 1KHz: > 1E11 Jones /Peak D* @ 1KHz: > 0.75E10 Jones	Average D*: ~5.5E13 Jones (3.74 – 4.61 μm) / (Johnson Noise Limited Peak D*: 1.79E12 Jones @ 14.484 μm (400 μm dia. & -40 mV))	Peak D* @ 4.65 μm: 3.0E11 Jones @ 98K
		Average D*: ~3.5E12 Jones (6.20 – 8.22 μm)	Peak D* @ 8.26 μm: 7.7E10 Jones @ 98K
		Average D*: ~6.5E11 Jones (8.80 – 13.75 μm)	Peak D* @ 14.01 μm: 2.4E10 Jones @ 81K
		PC AIRS HgCdTe Spectral Range: 13.75 – 15.4 μm, Size: 35 μm x 800 μm	
		Average D*: ~7E11 Jones (13.75 – 15.4 μm)	
Operating Temperature	77K	58K (AIRS)/60K (AIRS Light)	98K (SWIR/MWIR) 81K (LWIR)

A.3 GaAs/AlGaAs Quantum Well Infrared Photodetector (QWIP)

Recently, the GaAs/AlGaAs quantum well photodetector attracted a lot of attention for applications to atmospheric remote sensing in the 3- to 15- μm wavelength range. LWIR and VLWIR (8-9 and 14-15- μm) two-color imaging camera based on a 640x486 dual-band QWIP FPA have been demonstrated by Jet Propulsion Laboratory¹⁶. Subsequently, Goddard Space Flight Center, Jet Propulsion Laboratory, and Army Research Laboratory with a joint effort demonstrated a four-band, hyperspectral, and 640x512 QWIP array for NASA Earth Science mission^{6, 17}. This QWIP FPA has been developed for an imaging interferometer based on InGaAs/GaAs/AlGaAs material system. This produces the spectral range from 3 to 15.4- μm . This FPA consists of four independently readable IR bands and these are (1) 3 - 5- μm , (2) 8.5 - 10- μm , (3) 10 - 12- μm , and (4) 14 - 15.4- μm . Each band occupies 640x128 pixel area within the single imaging array. This detector array operates at 45K and shows a very high $D^* > 1 \times 10^{11}$ cm-sqrt (Hz)/W for each band. JPL has fabricated this four band QWIP array using the similar concept as the two-band system previously developed¹⁶.

B. Far-IR Detectors

In this section, we will emphasize on pyroelectric, Si bolometer, Si BIB detector and Antenna Coupled Terahertz Detector (ACTD) and their performances. The capability to reliably fabricate detectors that can respond to 10 - 50 μm (goal 3 - 100 μm) and 15 - 50 μm wavelength regions under Far Infrared Extended Blocked Impurity Band (FIREBIB) and Antenna Coupled Terahertz Detector (ACTD) development efforts has potential interest in future far infrared atmospheric remote sensing. The existing and under development far infrared detectors and their characteristics are discussed in the following subsections.

B.1 Pyroelectric Detector

Commercially available uncooled pyroelectric detectors present broadband capability in the 1 - 1000 μm wavelength range. Different types of pyroelectric detectors, such as LiTaO₃, LiNbO₃, and DLATGS are commercially available for far infrared applications. Among them, DLATGS (deuterated L-alanine doped triglycine sulphate) has already demonstrated in the FTS instruments due to its high sensitivity. This DLATGS pyroelectric detector has higher operating temperature, space heritage, lower cost, and moderate detectivity.

SELEX Sensors and Airborne Systems Limited is the manufacturer of DLATGS detectors in the 1 - 1000 μm and ambient temperature operation for Infrared spectrometers. This company develops pyroelectric detector material that can survive at higher operating temperature (around 59°C, Curie temperature). The DLATGS detector element and very high internal impedance are integrated with Junction Field Effect Transistor (JFET) amplifier. These are sealed and encapsulated within a TO-5 package and thermo-electric stabilized DLATGS IR detectors packages as discussed in ref.²¹. In addition, this SELEX Galileo builds this pyroelectric detector in a range of element sizes with options of CsI window or without window and high performance characteristics.

Six DTGS pyroelectric detectors (each detector diameter is 1.75 μm) from Barnes Engineering and single DTGS pyroelectric detector (2.0 μm diameter) from GEC-Marconi (now, called SELEX GALILEO) were used for Thermal Emission Spectrometer (TES) for Orbital Mars Global Surveyor¹⁸ and Mini- Thermal Emission Spectrometer (Mini-TES) for Mars Rover¹⁹ missions, respectively. Two uncooled DLATGS pyroelectric detectors stabilized at 25°C have been used in Radiation Explorer in the Far Infrared (REFIR)

interferometer instrument. Measurement has been made from a stratospheric balloon in tropical region using a Fourier transform spectrometer, during a field campaign held in Brazil in June 2005²⁰.

Performance Characteristics of DLATGS Detector for Far IR region²¹:

Parameters	Value
IR Wavelength Range	1- to 1000-micron
Detector Material	DLATGS (Deuterated L-alanine doped Triglycine Sulfate)
Operating Temperature	298K
Element Active Area Diameter	2 mm
Frequency Range of Operation	10 Hz to > 3 kHz
Thermal Time Constant	18 ms
Detector Window	CsI or Diamond

The noise equivalent power (NEP) values appearing in the next table is calculated using the following equation:

$$NEP = \sqrt{A}/D^*$$

The NEP is expressed in $W/Hz^{1/2}$ and is proportional to \sqrt{A} , NEP is dependent on area, but D^* doesn't; and A is the active area of the detector. Typical Performance Data for 2 mm diameter element without window for DLATGS Detector within 99 Series (one type of high performance DLATGS detectors)²¹:

Frequency (Hz)	Responsivity (V/W) (Typical)	Detectivity, D^* (cm. $Hz^{1/2}/W$) (Typical)	Noise Equivalent Power, NEP ($W/Hz^{1/2}$) (Typical)
10	2440	6.6E+8	2.7E-10
100	300	6.6E+8	2.7E-10
1000	30	3.5E+8	5.1E-10

B.2 Si Bolometer

Cooled silicon bolometers demonstrate broadband capability in the 1 – 1000 μm wavelength range. Conversely, Si bolometers are easier to fabricate with high operability, good uniformity, and lower cost, but has lower operating temperature (e.g., Liquid Helium, 4.2K). Cryogenically cooled silicon bolometers (discrete and array) offer nearly flat response. Noise Equivalent Power (NEP) goes down quickly as detector is cooled down ($4.2 - 0.3K$)²². Broadband Si bolometers consist of a doped silicon element and these bolometers approach the sensitivity limits of thermal detectors when cooled to liquid helium temperatures (<4.2K). During fabrication of these detectors, area, operating temperature, thermal time constant, and thermal conductance are adjusted to meet the specific design

requirements²³. Detector performance increases as the operating temperature is lowered. The performance specifications of silicon bolometer developed by Infrared Laboratory, Inc. are tabulated in Table 2.

B.3 Silicon Blocked Impurity Band Detector

DRS Technologies has demonstrated a longer cut-off wavelength of the BIB detector under Far Infrared Detector Technology Advancement Partnership (FIDTAP) within NASA Innovative Partnership Program. Figure 5 shows the standard BIB, demonstrated extended wavelength BIB, and also planned extended wavelength BIB detectors. Conventionally designed and processed Si:As BIB detectors have a cut-off wavelength of $\sim 28 \mu\text{m}$. FIDTAP program fabricated and tested Si:As BIB detectors with wavelength extension to approximately $50 \mu\text{m}$ ²³. Figure 5b shows the spectral response of this detector. The spectral response curve of FIDTAP developed detector (Figure 5b) is compared with respect to a conventional Si:As BIB detector and a model simulated spectral response curves as shown in Figures 5a and 5c. This FIDTAP study also shows promise for the extension of the wavelength beyond $50\text{-}\mu\text{m}$.

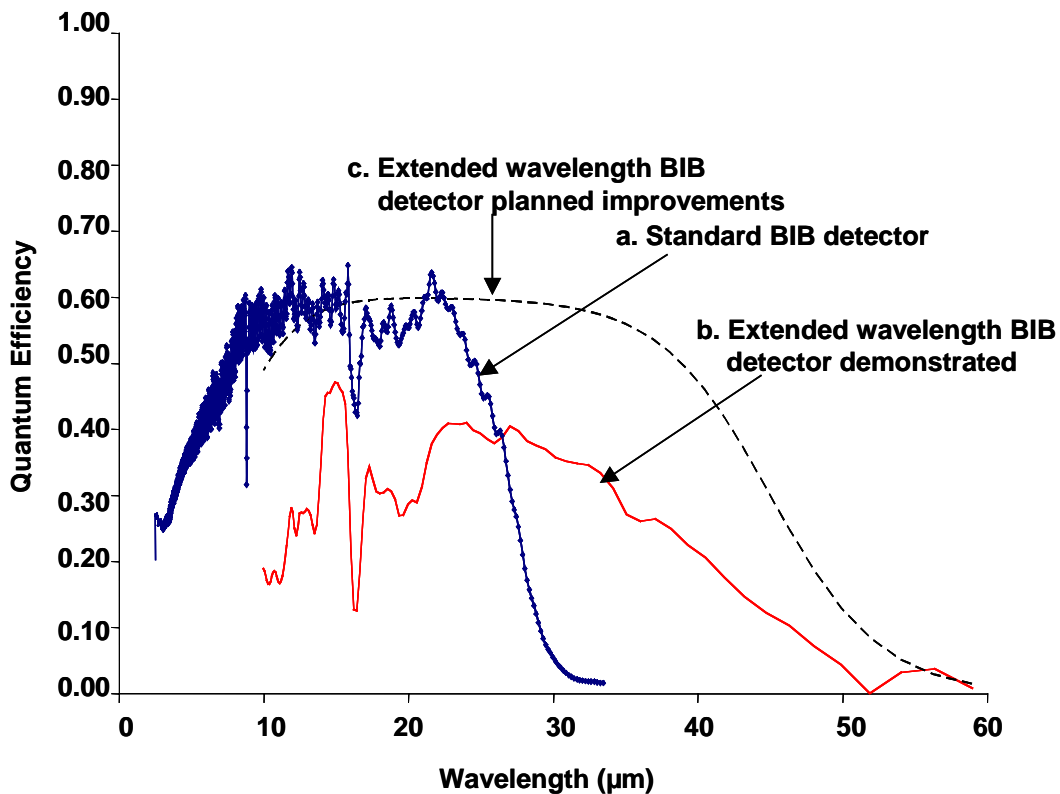


Figure 5. Wavelength extension demonstrated for Si:As detectors by development work conducted under FIDTAP²³. Figures 5a, 5b, and 5c are the standard BIB, demonstrated extended wavelength BIB, and planned extended wavelength BIB detectors.

Hence, NASA Langley Research Center with partnerships at DRS Sensors and Targeting Systems is developing the Far Infrared Extended BIB (FIREBIB) detector under the Advanced Component Technology (ACT) program. The proposed broadband detector in the 10- to $50\text{-}\mu\text{m}$ (goal 3- to $100\text{-}\mu\text{m}$) will be based on the As doped Si BIB detectors to operate

at 10 to 12 K. The performance characteristics of this FIREBIB detector are discussed in Table 2.

B.4 Antenna Coupled Terahertz Detectors

NASA Langley Research Center, in collaboration with Raytheon Vision Systems, is developing an antenna coupled terahertz detector within Calibrated Observation of Radiance Spectra from the Atmosphere in the far-Infrared (CORSAIR) IIP. The goal of this program is to fabricate detectors that can respond to 15- to 50- μm wavelength regions. This will allow us to optimize the detectors for each region of operation to achieve high detectivity and low NEP. This antenna coupled terahertz detector operates at 300K and may support the CLARREO far IR regions. The performance parameters of these detectors are given below in Table 2, too.

SELEX pyroelectric²¹ and Infrared Laboratories' Si Bolometer²² performance specifications and DRS' Far Infrared Extended Blocked Impurity Band (FIREBIB) Detector and Raytheon's Antenna Coupled Terahertz Detector anticipated performance characteristics are tabulated in Table 2.

Table 2

Detector Type Parameter	DLATGS Pyroelectric Detector (SELEX GALILEO)	Si Bolometer (IR Labs, Inc.)	Si BIB Detector (DRS) under Development	Antenna Coupled Terahertz Detector (RVS) under Development
Operating Temperature	298 K	4.2K – 0.3K	10 – 12 K	Uncooled
Window	CsI or No window			
Frequency Range	10 Hz to 3 KHz			
Active Area	2 mm dia.	6.25E-4 cm ²	200 μm x 200 μm	0.15 μm x 0.15 μm
Spectral Range	15 - 50 μm	2 – 3000 μm	10 – 50 μm (goal 100 μm)	15 - 50 μm
Detectivity	6.6E8 Jones @ 10 Hz	NEP @ 4.2K: 1E-13 W/sqrt (Hz)	1E10 Jones (goal >1E11 Jones)	~1E10 Jones (theoretical prediction)
	6.6E8 Jones @ 100 Hz	NEP @ 1.2K: 3E-15 W/sqrt (Hz)		
	3.5E8 Jones @ 1KHz	NEP @ 0.3K: 2.4E-16 W/sqrt (Hz)		
Thermal Time Constant	18 ms			

III. CONCLUSION

Broadband detector technology is rapidly advancing on a number of exciting applications, such as atmospheric remote sensing and astronomy, military, homeland security and medical imaging. HgCdTe and QWIP technology is expanding in the narrow band to broadband detectors, for example, mid-infrared range (3- to 16- μm). InSb/HgCdTe sandwich detectors and HgCdTe detectors already have demonstrated for applications to PARIS-IR

interferometer; and subsequently AIRS grating and IASI/CrIS FTS instruments. In addition, uncooled pyroelectric detectors and cooled Si bolometer have been demonstrated in the short wave infrared to far infrared wavelength range with high sensitivity as thermal detectors, which were utilized in REFIR and Mini-TES; and FIRST instruments. Development of broadband detectors will continue and FIREBIB and ACTD detectors will be demonstrated in near future. However, an increasing interest in broadband detection technology is materializing in the short wave-to-Far infrared with the feasibility of single element to two-dimensional arrays. Finally, this broadband detector will eliminate the requirements of three-to-four narrow-band detectors in a system, which potentially results in a reduction of power, cooling, weight, size, and cost of the overall detection system.

ACKNOWLEDGMENT

This effort is part of the CLARREO IR instrument and CORSAIR IIP funded by NASA's Earth Science Technology Office and the Enabling Concepts and Technology Program within NASA's Science Mission Directorate. The first author would like to thank Dr. Marion Reine and Dr. Kevin Maschhoff from BAE Systems; Dr. Arvind D'Souza and Ms. Stacy Masterjohn from DRS Sensors and Targeting Systems to give permission to include data & Figures from previous SPIE and JEM (Journal of Electronics Materials) papers on HgCdTe detectors in this review paper. The author also thanks to Dr. Norman Barnes, Dr. David G. Johnson, and Mr. Alan D. Little to read the manuscript and to provide some valuable suggestions.

REFERENCES

1. NRC Earth Science and Applications from Space, National Imperatives for the next decade and beyond, National Research Council, The National Academy of Sciences, 2007.
2. D. Fua, K.A. Walkera, K. Sunga, C.D. Boonea, M. -A. Soucyb, P.F. Bernatha, "The portable atmospheric research interferometric spectrometer for the infrared, PARIS-IR", *Journal of Quantitative Spectroscopy & Radiative Transfer* 103 (2007) 362–370.
3. M. Royer, D. Lorans, I. Bishchoff, D. Gotta, and M. Wolny, "IR detectors for the IASI instrument payload for the METOP-1 ESA polar platform", *Proc. SPIE*, Vol. 2312, pp. 251-261 (1994).
4. Paul Morse, Jerry Bates, Christopher Miller, Moustafa Chahine, Fred O'Callaghan, H.H. Aumaim and Avi Karnik, "Development and Test of the Atmospheric Infrared Sounder (AIRS)", *Proc. of SPIE* Vol. 3759, pp.236-253 (1999).
5. H.J. Bloom, "The Cross-track Infrared Sounder (CrIS): a sensor for operational meteorological remote sensing", *Geoscience and remote sensing symposium*, Vol. 3, pp. 1341 –1343 (2001).
6. S.V. Bandara, S.D. Gunapala, J.K. Liu, S.B. Rafol, D.Z. Ting, J.M. Mumolo, R.W. Chuang, T.Q. Trinh, J.H. Liu, K.K. Choi, M. Jhabvala, J.M. Fastenau, W.K. Liu, "Four-band Quantum Well Infrared Photodetector Array", *Infrared Physics and Technology* 44, pp. 369-375 (2003).
7. M.G. Mlynczak, D.G. Johnson, H. Latvakoski, K. Jucks, M. Watson, D.P. Kratz, G. Bingham, W.A. Traub, S.J. Wellard, C.R. Hyde, X. Liu, "First light from the Far-Infrared Spectroscopy of the Troposphere (FIRST) instrument", *Geophysical Research Letters*, Vol. 33, L07704, 2006.
8. G. Bianchini and L. Palchetti, "Technical Note: REFIR-PAD level 1 data analysis and performance characterization", *Atmos. Chem. Phys.*, Vol. 8, pp. 3817 – 3826 (2008).

9. NASA Contract# NNL08AA49C for ACTD detector development under CORSAIR IIP and Contract# NNL09AA12C for FIREBIB detector development under ACT program.
10. M.N. Abedin, T.F. Refaat, J.M. Zawodny, S.P. Sandford, U.N. Singh, S.V. Bandara, S.D. Gunapala, and I.B. Bhat, "Multicolor Focal Plane Array Detector: A Review", *Proc. SPIE* Vol. 5152, pp. 279 – 288 (2003).
11. Teledyne Judson Technologies Website on InSb/MCT detector technology (http://www.judsontechnologies.com/mercadm_pc.html) and also private communication. InSb/MCT Sandwich Detector Price Quote (Q25651), Aug. 18, 2009.
12. Kevin R. Maschhoff, "AIRS-Light Instrument Concept and Critical Technology Development", *Proceedings of SPIE* Vol. 4818 (2002), pp. 242-249.
13. P.S. Wijewarnasuriya, M. Zandian, J. Phillips, D. Edwall, R.E. DeWames, G. Hildebrandt, J. Bajaj and J.M. Arias, A.I. D'Souza, and F. Moore, "Advances in Large Area Hg_{1-x}Cd_xTe Photovoltaic Detectors for Remote Sensing Applications", *Journal of Electronics Materials*, Vol. 31 (7), pp. 726-731, (2002).
14. M. B. Reine, E. E. Krueger, P. O'Dette, C. L. Terzis, B. Denley, J. Hartley, J. Rutter and D. E. Kleinmann, "Advances in 15 micron HgCdTe photovoltaic and photoconductive detector technology for remote sensing", *SPIE* Vol. 2816, pp. 120-137 (1996).
15. S. Masterjohn, A.I. D'Souza, L.C. Dawson, P.N. Dolan, G. Jefferson, M.G. Stapelbroek, R.W. Willis, P.S. Wijewarnasuriya, E. Boehmer, J. Ehlert, J.E. Andrews, "Cross-Track Infrared Sounder FPAA Performance", *Proc. of SPIE* Vol. 5655, pp. 343 – 352 (2005).
16. S.D. Gunapala, S.V. Bandara, A. Singh, J.K. Liu, S.B. Rafol, E.M. Luong, J.M. Mumolo, N.Q. Tran, J.D. Vincent, C.A. Shott, J. Long, and P.D. LeVan, "8-9 and 14-15-micron two-color 640x486 quantum well infrared photodetector (QWIP) focal plane array camera", *Proc. SPIE* 3698 (1999), pp. 687-697.
17. M. Jhabvala, "Application of GaAs quantum well infrared photoconductors at the NASA/Goddard Space Flight Center", *Infrared Phys. & Tech.* 42 (2001), pp. 363-376.
18. P. R. Christensen, J. L. Bandfield, V. E. Hamilton, S. W. Ruff, H. H. Kieffer, T. N. Titus, M. C. Malin, R. V. Morris, M. D. Lane, R. L. Clark, B. M. Jakosky, M. T. Mellon, J. C. Pearl, B. J. Conrath, M. D. Smith, R. T. Clancy, R. O. Kuzmin, T. Roush, G. L. Mehall, N. Gorelick, K. Bender, K. Murray, S. Dason, E. Greene, S. Silverman, and M. Greenfield, "Mars Global Surveyor Thermal Emission Spectrometer experiment: Investigation description and surface science results", *JOURNAL OF GEOPHYSICAL RESEARCH*, VOL. 106, NO. E10, PAGES 23,823–23,871, OCTOBER 25, 2001.
19. S. Silverman, R. Peralta, P. Christensen, G. Mehall, "Miniature thermal emission spectrometer for the Mars Exploration Rover", *Acta Astronautica*, Vol. 59, pp. 990-999 (2006).
20. Palchetti, et al., "Technical Note: First spectral measurement of the Earth's upwelling emission using an uncooled wideband Fourier transform spectrometer", *Atmos. Chem. Phys.*, Vol. 6, pp. 5025-5030 (2006).
21. SELEX GALILEO Website-http://www.selex-sas.com/EN/Common/files/SELEX_Galileo/Products/DLATGS_dsh.pdf.
22. Infrared Laboratories, Inc. and WebSite- <http://www.infraredlaboratories.com/>.
23. H. H. Hogue, M. G. Mlynchak, M. N. Abedin, S. A. Masterjohn, and J. E. Huffman, "Far-infrared detector development for space-based Earth observation", *Proc. of SPIE* Vol. 7082, pp. 70820E-1 – 70820E-8, (2008).