Emerging Trends in IRFPA Sensors

Sudha Gupta, R.K. Sharma and P.K. Basu
Solid State Physics Laboratory, Delhi-110054, India

Abstract

Significant developments have been taking place in the field of infrared sensors in recent years, to achieve higher resolution, wider spectral range, shorter response time and higher sensitivity (lower noise) in thermal imaging systems. Efforts are on to develop new technologies to produce infrared focal plane arrays (IR FPAs) with smaller pixel pitches, larger formats, higher frame rates, larger dynamic range and multicolor detection. In addition to these factors, reduction in cost, increase in IRFPA operating temperature to reduce cryogenic constraints and improvement in reliability are other driving forces for developing new technologies. Efforts in IR detector development have resulted in emergence of newer detector materials/technologies and in further device engineering of existing materials. Emergence of MEMS based IR detectors in the last decade has been one of the most significant developments in the field of uncooled detectors.

Here we present a brief review of the recent developments in IRFPA technologies including detector materials and device architectures, utilized for both cooled and uncooled operations. The basic principles of various devices are briefly discussed and their performance is compared. Mercury cadmium telluride (MCT) based IR detectors have remained highest performance detectors for decades and is still the material of choice for achieving highest performance. The challenges posed by alternate technologies based on III-V compound semiconductors like InSb, GaInAs, QWIP and type-II strained layer superlattice structures are also discussed. Future trends for multi-spectral IR detectors and development of adaptive focal plane arrays is also discussed.

Key words: infrared focal plane arrays, dynamic range, readout integrated circuit, multi-spectral IR detectors, and adaptive focal plane arrays.

1. Introduction:

IR FPAs find extensive military applications in reconnaissance, surveillance, missile guidance and thermal imaging apart from a variety of civilian (fire fighting, pollution monitoring, remote sensing, etc.), medical (thermography, tumor detection, etc.), industrial (non-destructive testing, process monitoring, etc.) and astronomical applications. New trends in the development of IRFPA technology aim at achieving highest performance (with large 2-D format) cooled IR FPAs to get maximum possible sensor range, resolution and sensitivity on one hand, while on the other hand they seek to produce low priced, high reliability, uncooled sensors of smaller size and weight. Also playing an increasing role in cooled and uncooled IR FPA systems are the emerging multi-spectral sensors, which provide a lot more information than mono-spectral sensors. In addition, the use of 3D active imagery is anticipated to improve identification range and efficiency. In short, futuristic IR systems have to provide following capabilities:

- High sensitivity and, consequently, high thermal contrast of the collected image.
- Large formats of detectors with high uniformity across the detector array
- Multispectral detection (MWIR/LWIR) and lower cross-talk.
- Operation at higher FPA temperatures (>200K) to reduce cryogenics constraints and to improve reliability
- The decrease in global system cost
- Lower pixel size

IR FPA improvements are mainly derived from improvements of detector and ROIC technologies. The detector part converts the IR (optical) signal from the target into the electrical signal whereas ROIC provides signal multiplexing, image processing and electrical interface to the imaging system. Detector and ROIC parts of the FPA can be implemented as either one chip (monolithic) or as a two-chip (hybrid) assembly. Generally, cooled FPAs are made hybrid type with silicon based ROIC and detector material optimized to sense in the IR region (fig. 1a) while uncooled FPAs are mostly monolithic type (fig. 1b). Current trend in the IRFPA technology is characterized by (i) very large format (1024 × 1024, 1280 × 1024) cooled arrays with enhanced capabilities like higher frame rates, better thermal resolution etc. and (ii) uncooled microbolometer based thermal detectors useful for short range (< 1Km). They have an advantage of drastic reduction in size, power requirement and cost. These are finding extensive applications for shoulder fired missile seeker and thermal weapon sight.

As a result of continuous research, a wide variety of detector types, employing different physical principles, operating with high sensitivity in the IR spectrum region have been developed. The great majority of these devices use semiconducting materials. Use of alloy semiconductors has allowed tailoring of device properties, particularly the wavelength response. Mercury cadmium telluride (MCT) is the most important semiconductor alloy which has produced highest performance devices for nearly four decades in LWIR, MWIR and SWIR wavelength bands (these are the three most significant bands for room temperature thermal imaging). Sensitivity in different bands is achieved by simply varying the alloy composition. During eighties and early nineties, the major emphasis worldwide remained on the development of MCT IRFPAs in the LWIR band. But the acute metallurgical and physical problems associated with this material encouraged scientists to explore alternate materials/technologies also in LWIR, MWIR and SWIR bands. However, out of numerous efforts, initially the PtSi (SWIR and MWIR bands) based Schottky diodes and GaAs based quantum well IR photodetectors (QWIP- both MWIR and LWIR bands) and later InSb (MWIR) based FPAs proved most successful. Another technology which is still in the development stage, but holds the potential to compete with MCT detectors in LWIR band, is antimonide based strained layer superlattices. We will discuss various detector types and materials in the next section. ROIC development addresses to cope up with the reduced pitch size with maintaining optimum charge handling capacity and adding more and more functions needed to improve the general FPA performance including intelligence. These developments are very important since detector development has reached such a stage that main performance limitations are now due to readout circuits. ROIC developments are described in more details in section 3.

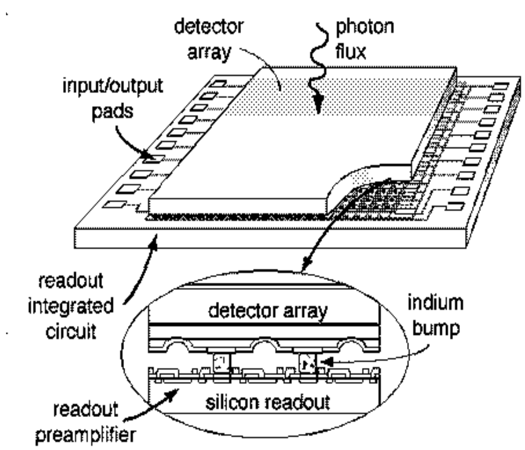

Figure1(a) Schematic of a hybrid IR FPA. All pixels of the detector array and ROIC are connected via indium bumps.

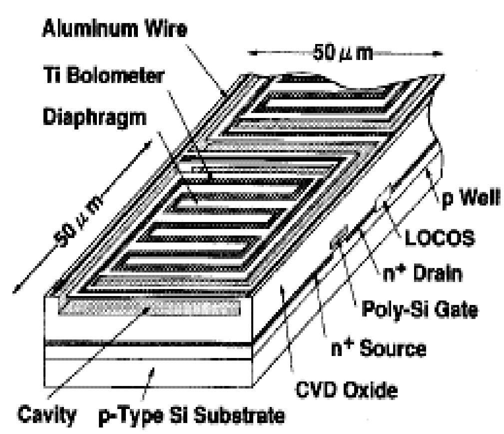

Figure 1(b). Pixel structure for monolithic titanium bolometer IR FPA. Cavities and diaphragms are formed over the ROIC.

2. IR Detectors – Material & Devices

There has been tremendous progress in IR detector materials and device structures in the last four decades. Some of these are described briefly below:

2.1 Development of IR detectors

Many materials have been investigated in the IR field. Many of these IR materials are based on compound semiconductors made of III-V elements such as indium, gallium, arsenic, antimony, or on the II-VI elements mercury, cadmium and tellurium, or on the IV-VI elements lead, sulfur and selenium. They can be combined into binary compounds such as GaAs, InSb, PbS and PbSe or into ternaries such as InGaAs or HgCdTe. The requirement is that the associated physical phenomena for IR detection should lie in the range of about 0.1–1.0 eV. A figure of merit used for comparing various IR detectors is D*. Theoretical curves for the background-limited *D** for a variety of IR materials as ideal photovoltaic and photoconductive or thermal detectors are shown in figure 2 [1].

The IR detectors can be broadly divided into two categories depending on their detection mechanism: (i) **Thermal detectors**: In these detectors, the incident IR radiation is absorbed and raises the temperature of the material. The output signal is observed as a change in some temperature dependent property of the material. Since the increase in temperature is independent of the incident radiation wavelength, the response of these detectors does not show spectral dependence. These detectors do not require cryogenic cooling and hence are cheaper, smaller, light weight, require less power and are more reliable than photon detectors. (ii) **Photon detectors**: In these detectors, the incident photons are absorbed within the material by interaction with electrons. The observed electrical signal results from the changed electronic energy distribution. Since absorption in this case depends on the wavelength of the incident photons, these detectors show spectral dependence. These detectors show higher sensitivity and smaller response time as compared to thermal detectors.

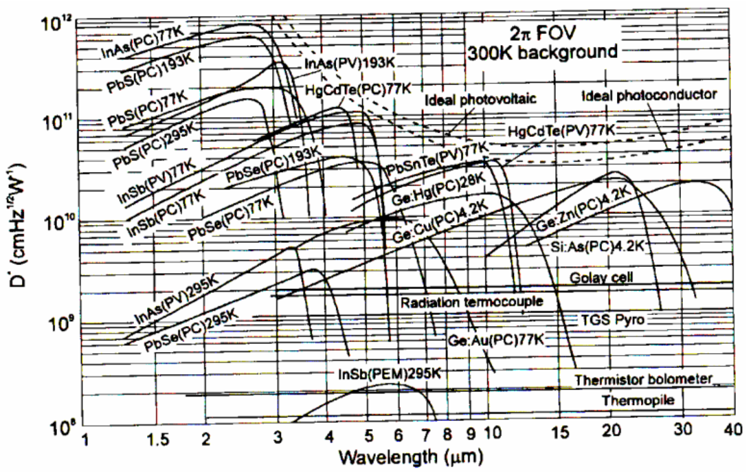

Fig. 2. Comparison of the *D** of various commercially available infrared detectors when operated at the indicated temperature. Chopping frequency is 1000 Hz for all detectors except the thermopile (10 Hz), thermocouple (10 Hz), thermistor bolometer (10 Hz), Golay cell (10 Hz) and pyroelectric detector (10 Hz). Each detector is assumed to view a hemispherical surround at a temperature of 300 K.

2.1.1 Thermal detectors

Recent advances in micro-electromechanical (MEMS) technology has led to rapid developments in high performance and low cost uncooled thermal detector based FPAs opening the way for wider utilization for both military and commercial applications. Use of MEMS technology has now made it possible to obtain better thermal isolation between the thermal sensitive element and its associated substrate. Two commonly used methods for achieving thermal isolation include subtractive chemical etching and the additive deposition of sacrificial materials.

Thermal detectors are classified on the basis of the property that is changed with the rise in temperature due to the absorption of the incident radiation. The signal is obtained by measuring the change in that property. The most important detection mechanisms used are resistance change (bolometers), change in internal electrical polarization (pyroelectric detectors) and thermoelectric effect (thermoelectric detectors). Other detection mechanisms include oil film evaporation (evaporagraph), semiconductor absorption edge shift, thermoelastic effect, liquid crystal color change and gas pressure change (Golay cell). The bench-mark of the technology can be taken as size and sensitivity of detector arrays. Sensitivity is reflected by the parameter noise equivalent temperature difference (NETD). Presently the technology of bolometer arrays is in the most advanced stage among thermal detectors. Sincere efforts in other technologies are also going on and in future they may also provide tough competition to produce third generation FPAs.

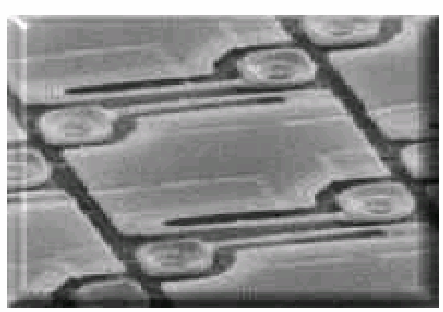
Figure 3: magnified view of an α-silicon based bolometer detector array.

Bolometer detector arrays: The operating principle of bolometer detectors is that the temperature change caused by the absorption of IR radiation leads to a change in electrical resistance of the material. The resistance change is readout as a change in voltage across the resistive element. The sensitive area of each pixel of the bolometer array is thermally isolated from the substrate by using MEMS technology. Detector structure of a α-silicon based bolometer detector array using the micromachining technology is shown in figure 2(a). Larger conductivity in bolometer detectors ensures faster response but reduces the sensitivity to temperature change. Thus, there is generally a trade-off between the two. Most of the cameras available in the commercial market are bolometer based. NEC Japan, started with titanium as bolometer material, is now working on vanadium oxide (VO_x) as well. CEA-LETI has recently reported α-Si based 320 × 240 monolithic FPA of array pitch 25μm, response time 7ms and NETD 78mK. IR absorption is reported to be >80% [2]. Honeywell has reported high performance VO_x based arrays of pitch 37μm with NETD value 100mK and response time of 12ms. Raytheon (RVS) has made a significant breakthrough in the development of 640 × 512 array with a unit cell size of 20μm × 20μm, 30 Hz frame rate and <20mK NETD [3]. The Texas Instruments, USA offers a hybrid array that contains ferroelectric material (barium strontium titanate) In-bump bonded to a Si- ROIC. The array size is 245 × 328, pitch is 48.5μm and NETD achieved is <47mK. This technology is now used by Raytheon Commercial Infrared [4].

The superconducting materials for bolometeric applications are also under development [5]. The dramatic resistance change versus temperature in superconducting material like YBaCuO leads to a high sensitivity of bolometer detectors.

Pyroelectric detector arrays: Pyroelectric materials are attractive for IR detection due to their ability to spontaneously produce charge with a temperature change and their inherent low electrical noise. The three most extensively used materials, compatible with micromachining isolation microstructures are zinc oxide (ZnO), lead titanate ($PbTiO_3$) and lead zirconium titanate (PZT). The progress of these devices is mostly hindered by processing problems. Prototype 64 × 64 arrays have been demonstrated by University of Minnesota with a pitch of 75μm and specific detectivity of $2 \times 10^8 cmHz^{1/2}/W$ [6].

A thermoelectric device (thermocouple or thermopile) is based on the presence of one or several junctions between two materials. The junctions properly arranged and connected develop a thermo-emf that changes with temperature, the so called Seebeck effect. In order for the sensitivity to be high the Seebeck coefficient should be as high as possible. Certain alloys containing antimony and bismuth possess very high Seebeck coefficients of ~150 μV/K. The CMOS compatible combination aluminum/polycrystalline silicon gives about ~65 μV/K.

2.1.2 Photon detectors

Progress in IR detector technology is connected mainly to semiconductor IR detectors, which are included in the class of photon detectors. Electron interaction with the incident radiation follows one of the mechanisms shown in figure 4. Since the photon absorption depends on the incident photon energy, the

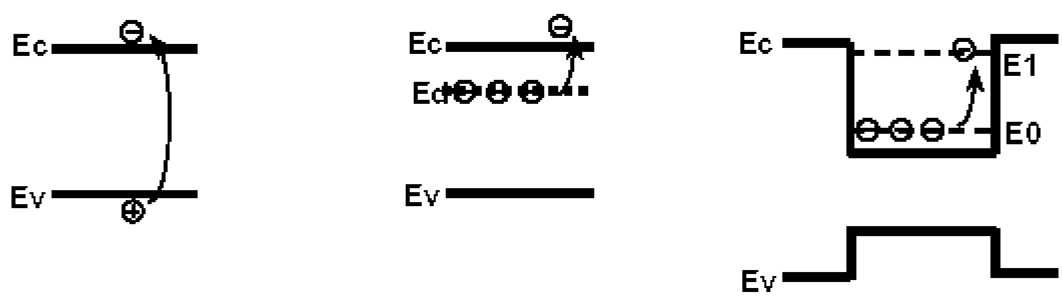

Figure 4: Electron interaction in photon detectors with the incident IR radiation

photon detectors show a selective wavelength dependence of the response per unit incident radiation power. They exhibit both higher signal-to-noise performance and a very fast response. But to achieve this, the photon detectors require cryogenic cooling. Cooling requirements are the main obstacle to the more widespread use of IR systems based on semiconductor photodetectors making them bulky, heavy, expensive and inconvenient to use. Depending on the nature of interaction of the material with the radiation, the class of photon detectors is further sub-divided into different types. The most important are: photoemissive (metal silicide Schottky barriers) detectors, extrinsic detectors, quantum well detectors, intrinsic detectors and strained layer superlattice (SLS) typeII detectors.

Photoemissive detectors: PtSi Schottky-barrier detector is the most popular one in this category of detectors. Radiation is transmitted through the p-type silicon and is absorbed in the metal PtSi, producing hot holes which are then emitted over the potential barrier into the silicon, leaving the silicide charged negatively. The effective quantum efficiency in the 3–5μm atmospheric window is very low, of the order of 1%, but useful sensitivity is obtained by means of near full frame integration in area arrays. It has spatial uniformity characteristics that are far superior to those of other detector technologies. Uniformity is only limited by the geometric definition of the detectors. The 1040×1040 element CSD FPA has the smallest pixel size ($17\times17\mu m^2$) among 2D IR FPAs [7]. However, the performance of monolithic PtSi Schottky-barrier FPAs has almost reached a plateau and no further developments are expected in the near future.

Extrinsic photoresistors: These are used in a wide range of the IR spectrum extending from a few μm to ≈300 μm. They are the principal detectors operating in the range $\lambda > 20\mu m$. Detectors based on silicon and germanium have found the widest application as compared with extrinsic photodetectors on other materials. Although the potential of large extrinsic silicon FPAs for terrestrial applications has been examined, interest has declined in favor of HgCdTe and InSb with their more convenient operating temperatures. Strong interest in doped silicon continues for space applications, particularly in low-background flux and for wavelengths from 13 to 20μm, where compositional control is difficult for HgCdTe. The shallower impurity energies in germanium allow detectors with spectral response up to beyond 100μm wavelength and major interest still exists in extrinsic germanium for wavelengths beyond about 20μm. Blocked impurity band (BIB) devices made from either doped silicon or doped germanium, are sensitive in the IR wavelength range of 2 and 220 μm. BIB devices in large staring array formats are now becoming commercially available. The best results have been achieved to date for Si:As BIB hybrid FPAs produced by Hughes Technology Center in Carlsbad [8,9] and Rockwell International Science Center in Anaheim [10]. Hybrid FPAs with Si:As BIB detectors operating in 4–10K temperature range have been optimized for low, moderate, and high IR backgrounds. The 256×256 format with 30 μm pixels and 240×320 format with 50 μm pixels are available for low- and high-background applications, respectively. Antimony-doped silicon (Si:Sb) arrays and 128×128 pixel Si:Sb hybrid FPAs having response to wavelengths >40 μm have been also demonstrated, primarily for use at low and moderate backgrounds.

GaAs/AlGaAs QWIPs: Among the different types of quantum well IR photodetectors (QWIPs), technology of the GaAs/AlGaAs multiple quantum well detectors is the most mature. Detection of IR radiation is realized via intersubband or bound to extended-state-transitions within the multiple QW. A key factor in QWIP FPA performance is the light-coupling scheme. A distinct feature of QWIPs is that the optical absorption strength is proportional to an incident photon's electric-field polarization component normal to the quantum wells. For imaging, it is necessary to be able to couple light uniformly to 2D arrays of these detectors, so a diffraction grating or other similar structure is typically fabricated on one side of the detectors to redirect a normally incident photon into propagation angles more favorable for absorption. Even though QWIP is a photoconductor, several of its properties such as high impedance, fast response time, long integration time, and low power consumption, well comply to the requirements of large FPA fabrication. Due to the high material quality at low temperature, QWIP has potential advantages over HgCdTe for VLWIR FPA applications in terms of the array size, uniformity, yield and cost of the systems. The current state of the art for QWIP FPA size has been 640×480 recently demonstrated by JPL [11, 12] and Lockheed Martin [13]. The measured mean NEDT of the QWIP camera was 36mK at an operating temperature of 70 K at 300 K background [12].

Strained layer type-II superlattice detectors: The development of these detectors is largely motivated by the promise of achieving high performance detectors for VLWIR applications. In a type II superlattice structure, the forbidden regions of the energy gaps are staggered so that the conduction band of the narrow bangap semiconductor is lower in energy than the valence band of the wider band gap one. The staggered misalignment creates a potential for electrons in one layer and another potential for holes in the other layer. Because electrons and holes are confined to separate layers, the interband transitions are spatially indirect. If brought to maturity, detectors using these superlattices are expected to have comparable quantum efficiency yet lower dark current, thus, giving rise to very uniform array response. These detectors show potential to provide higher performance FPAs than MCT or QWIP detectors and also expected to achieve higher operating temperatures. InAs/GaInSb is the most studied structure where several researchers have verified the quantum reduced energy gap [14]. 256 × 256 SL FPA has been reported to have shown NEDT of ~10mK with f/2 optics and integration time 5ms [15].

InGaAs photodiodes: $In_xGa_{1-x}As$ (InGaAs) photodetectors are used in 1–1.7μm wavelength region (x=0.53) for high-speed, low-noise light wave communication systems. $In_{0.53}Ga_{0.47}As$ alloy is lattice matched to the InP substrate. Having lower dark current and noise than indirect-band-gap germanium, the competing near-IR material, the material is addressing both entrenched applications including low light level night vision and new applications such as remote sensing, eye-safe range finding and process control [16]. By changing the alloy composition of the InGaAs absorption layer, the photodetector responsivity can be maximized at the desired wavelength of the end user to enhance the signal-to-noise ratio. Standard $In_{0.53}Ga_{0.47}As$ photodiodes have radiative-limited room temperature detectivity of $\sim 10^{13}$ cm $Hz^{1/2}$ W^{-1}. The highest quality InGaAs photodiodes have been grown by MOCVD [17]. Their performance is comparable with HgCdTe photodiodes. Linear array formats of 256, 512 and 1024 elements have been fabricated for environmental sensing from 0.8 to 2.6 μm. The size of pixels are different; from 30×30 μm^2 (with spacing of 50μm), 25×500 μm^2 to 13×500 μm^2 (with spacing of 25μm). Room temperature staring cameras based on 128×128 and 320×240 InGaAs FPAs have been fabricated.

Intrinsic detectors: This is the most important category which has produced highest performance arrays to date. Both HgCdTe and InSb photodetector arrays belong to this class. The cryogenically cooled InSb and HgCdTe arrays have comparable array size and pixel yield at MWIR spectral band. However, wavelength tunability and high quantum efficiency have made HgCdTe the preferred material.

InSb photodiodes: InSb material is far more mature than HgCdTe and good quality more than 7cm diameter bulk substrates are commercially available [18]. Epitaxy is not used; bulk n-type single crystal wafers are used for fabrication of photodiodes which can be operated in the temperature range above 77 K for imaging in the MWIR band. InSb photovoltaic detectors are widely used for ground-based IR astronomy and for applications aboard the Space Infrared Telescope Facility. Recently, impressive progress has been made in the performance of InSb hybrid FPAs. An array size of 1024×1024 is possible because the InSb detector material is thinned to <10 μm (after surface passivation and hybridisation to a readout chip) which allows it to accommodate the InSb/silicon thermal mismatch [19]. Linear array formats of 64, 128 and 256 elements are also produced with frontside-illuminated detectors for both high-background and astronomy applications. Element sizes depend on device format and range from 20×20 to 200×200μm.

HgCdTe photodiodes: During the past four decades mercury cadmium telluride (HgCdTe) has became the most important semiconductor for the short, middle and long wavelength (λ=3–30μm) IR photodetectors. In the SWIR region, Rockwell Science Center has reported the largest array of size 2048 × 2048, sensitive to 0.9-2.5μm radiation [20] that operates at an operating temperature of 120K. Sofradir has produced high performance 640 × 480 MWIR and 320 × 240 LWIR arrays with this material. It is also developing 1080 × 1024 MWIR arrays in the near future [21].

There have been numerous attempts to replace HgCdTe with alternative materials. The main motivations, behind the numerous attempts to replace HgCdTe, are technological problems of this material. One of them is weak Hg–Te bond, which results in bulk and surface and interface instabilities. Uniformity and yield are still issues. Nevertheless, HgCdTe remains the leading semiconductor for IR detectors. The most important reasons for this are:

- This material can yield highest quantum efficiency.
- It can be tailored for optimised detection at any region of IR spectrum, dual and multicolour devices can be easily constructed.
- Maximum operating temperatures, so far, for any of SWIR, MWIR or LWIR band has been achieved for HgCdTe photovoltaic detectors.
- The present development of IR photodetectors has been dominated by complex band-gap heterostructures. Among various variable band-gap semiconductor alloys, HgCdTe is the only one material covering the whole IR spectral range having nearly the same lattice parameter. The difference of lattice parameter between CdTe and $Hg_{0.8}Cd_{0.2}Te$ is ≈0.2%. The independence of lattice parameter on composition is a major advantage of HgCdTe over any other materials.

Highest performance devices achieved in HgCdTe epilayers are grown on CdZnTe (CZT) substrates. This places a constraint on the maximum size of the FPA that can subsequently be fabricated because bulk CZT wafers are not available in large sizes (above 30 cm^2 diameter). This is one of the main reasons why quest for alternate substrate materials, like silicon, GaAs, Ge etc. are being explored. The growth of MCT onto silicon wafers has become a hot topic of research and development [22]. This has additional advantages because of the lower price of silicon substrates and lesser thermal stress generation by cooling the device at the detector operating temperature. Array sizes are being pushed upwards and Sofradir has recently reported 1280 x 1024 MW 15μm pixel pitch detector array on germanium substrate which is affordable and answers to very high resolution system requirements. NETD is below 20mK at mid-dynamic range.

To sum up, HgCdTe is today the material of choice in several defense and security related laboratories. QWIP has become a strong contender in applications not requiring fast frame rates. Today only QWIP can deliver the highest pixel count in the LW spectral region. In the present scenario, most significant futuristic material technologies for IR FPAs appear to be HgCdTe, QWIP (GaAlAs/GaAs) and SLS. In the near term, HgCdTe or QWIP are the leading candidates while in the long term SLS materials appear to be quite promising. Relative advantages and disadvantages of various detector materials has been summarized by Rogalski [23] in the form of table I.

2.2 Multi-spectral IR Arrays: Multicolour capabilities are highly desirable for advance IR systems as one obtains data in separate IR spectral bands that can discriminate both absolute temperature and unique signatures of objects in the scene thereby significantly enhancing the acquisition of concealed targets. Advanced colour processing algorithms are developed to further improve sensitivity above that of single-colour devices. SLS, HgCdTe photodiodes and QWIPs possess the multi-band capability. While HgCdTe photodiodes and QWIPs show promise in LWIR and MWIR bands, SLS will be more suitable for LWIR and VLWIR bands. Currently, hyperpectral techniques are based on a reflected computed tomography imaging spectrometer in which a 2-D grating is used to generate an array of spectrally dispersed images of the scene on the FPA. The computational capabilities that are required to process the large amount of acquired data may lead to delays between image collection and the delivery of the processed information.

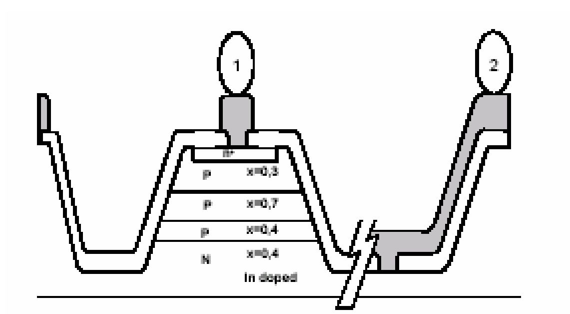

Figure 5 : Schematic cross-section of two-color detector structure

HgCdTe two-colour detector arrays are usually based upon HgCdTe triple layer heterojunction (TLHJ) design where two independent p-on-n diodes, with absorption in two different IR bands, are formed. Metal contacts from both the diodes on each pixel is made through two indium bumps deposited for bonding to the silicon ROIC. Band 1 and band 2 signals can be integrated and processed simultaneously, making the analysis of a thermal scene very fast. Fill factors of 128×128 MWIRI/MWIRII FPAs as high as 80% were achieved by using a single mesa structure to accommodate the two indium bump contacts required for each unit cell with 50 μm size [24]. The NEDT for both bands was below 25 mK and imagery was acquired at temperatures as high as 180 K with no visible degradation in image quality. The camera used for these measurements had a 50 mm, *f*/2.3 lens. 256 × 256 SW and MW (cut-off wavelength of 3.1μm and

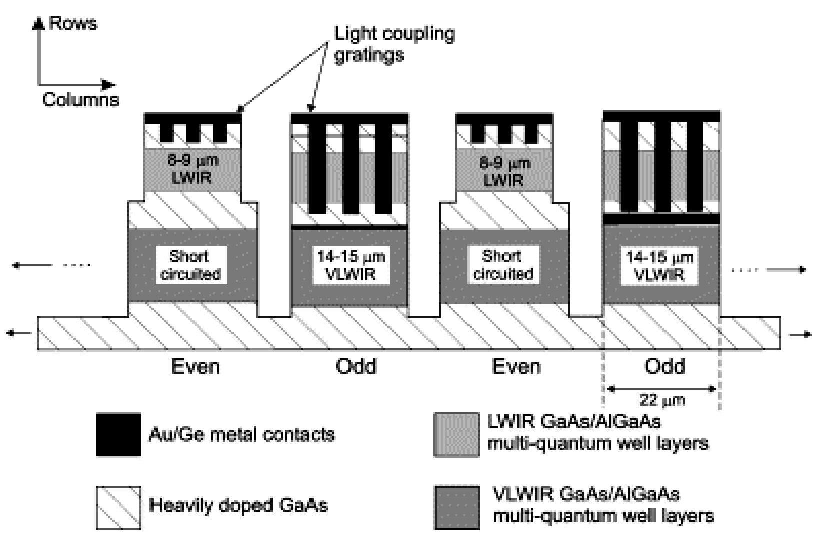

Figure 6. Structure cross-section of the interlace dual-band FPA

5.0 µm respectively) dual band FPA with 25 µm pitch has also been successfully demonstrated by Sofradir. NETD in the two bands is 50mK and 14mK [25].

Device capable of simultaneously detecting two separate wavelengths can also be fabricated by vertical stacking of the different QWIP layers during epitaxial growth (fig. 6). Separate bias voltages can be applied to each QWIP simultaneously via the doped contact layers that separate the multiple quantum well detector heterostructures. Typical operating temperature for QWIP detectors is in the region of 40–100 K. Two-colour detectors that cover both MWIR and LWIR atmospheric windows are especially important in many applications. To cover MWIR range a strained layer InGaAs/AlGaAs material system is used. InGaAs in MWIR stack produces high in-plane compressive strain which enhances the responsivity [26]. The MWIR/LWIR FPAs fabricated by Sanders consist of an 8.6 µm GaAs/AlGaAs QWIP on top of 4.7 µm strained InGaAs/GaAs/AlGaAs heterostructure. The fabrication process allowed fill factors of 85% and 80% for the MW and LW detectors. The first FPAs with this configuration had the operability in excess of 97%, and NETD value better 35 mK. Recently, Gunapala et al. [27] have demonstrated the first 8–9 and 14–15 µm two-colour imaging camera based on a 640×486 dual-band QWIP FPA, which can be processed with dual or triple contacts to access the CMOS readout multiplexer. Single indium bump per pixel is usable only in the case of interlace readout scheme (i.e., odd rows for one colour and the even rows for the other colour) which uses an existing single-colour CMOS readout multiplexer. However, the disadvantage is that it does not provide a full fill factor for both wavelength bands.

Table I: Advantages and Disadvantages of various detector materials

Detector Type	Advantages	Disadvantages
Thermal	Light, rugged, reliable and low cost Room temperature operation	Low detectivity at high frequency Slow response (ms order)
Photon Intrinsic		
IV-VI	Available low-gap materials Well established technology	Poor mechanical properties Large permittivity
II-VI	Easy band gap tailoring Well developed theory and experiment Multi-band (colour) detectors	Non-uniformity over large area High cost in growth and processing
III-V	Good materials and dopants Advanced technology Possible monolithic integration	Hetero-epitaxy with large lattice mismatch
Extrinsic	Very long wavelength operation Relatively simple technology	Extremely low temperature operation
Free Carriers	Low-cost, high yields Large and closed packed 2D arrays	Low quantum efficiency Low temperature operation
Type-I Quantum Well	Matured materials growth Good uniformity over large area	Low quantum efficiency Complicated design and growth
Type-II Quantum Well	Low Auger recombination rate Easy wavelength control	Complicated design and growth Sensitive to the interfaces

2.3 Adaptive FPA (AFPA)

These arrays improve upon the imaging quality and significantly increase the recognition and identification ranges by exploiting the spectral features in the imaged scene. An AFPA consists of an array of MEMS tunable filters, hybridized with a dual band (MWIR, LWIR) IRFPA. Optical thin film coatings integrated with the MEMS device define the spectral tuning range. The MEMS filters provide narrowband tuning in the LWIR and simultaneous broadband imaging in MWIR. Each filter is independently electrically addressable; enabling tailored spectral analysis of different regions in space.

Rockwell Science Center [28] is developing an imaging AFPA that will enable narrowband (100nm) spectral tuning in the LWIR (8.0-10.7μm) with simultaneous, broadband, pixel-registered imagery in the 3-5μm. A unique feature of this device is its ability to independently and simultaneously tune the spectral passbands of different spatial regions. RSC has demonstrated prototype filters in various sizes and formats and assembled them to validate the overall device architecture.

3. ROIC

FPA ROIC size has increased dramatically over time, initially tracking "Moore's Law" historical growth rate of doubling transistor count per device every two year, but more recently doubling approximately every four years. The choice of ROIC type, i.e., source follower per detector (SFD), direct injection (DI), buffered direct injection (BDI) or capacitance transimpedance amplifier (CTIA) depends upon factors such as expected operating background flux, noise re4quirement, detector type, dynamic range etc. For example, SFD is a very low noise input circuit widely used for astronomy, CTIA is a low noise high speed input circuit and DI is more suitable to mid to high background, high speed application.

Current trend in ROIC design caters to: (i) improving the charge handling capacity, especially in the case of LWIR detectors, (ii) increasing number of pixels as compatible with increasing number of detectors per array and at the same time use of larger frame rates (Sofradir has recently claimed to have produced 1280 x 1024 MW array with 15μm pitch and a frame rate of 120 Hz), (iii) increase in the number of outputs (more than four outputs), (iv) windowing and zooming facilities, (iv) two operating modes: integration then read (ITR) and integration while read (IWR), (v) minimizing power consumption, (vi) digital output etc. In addition the ROIC noise should be much less than the detector noise so that it does not contribute to the device NETD. Further, the development of two-colour or dual-band FPA requires separation of the two photocurrents and independent optimization of the two integration sites. This is achieved by two integration capacitors per unit cell. The most critical requirement of large format FPAs is that of large charge handling capacity as the size of each pixel is shrinking. Many innovative ideas are pursued in this direction. One of the most promising one is implementation of three dimensional (3-D) architecture of ROIC. This is made possible by stacking of ROIC layers together in 3-D (vertically integrated sensor array) and develop pixel to pixel interconnected silicon processors at the detectors, thus expanding the area available for signal and image processing without using the very small area on the FPA pixel itself [29]. The main advantages of this technology are: (i) increased charge storage, (ii) local processing at the detector and (iii) parallel signal manipulation.

4. Demand on Optical Systems

As FPAs become smarter and less expensive, demands on the optical systems increase. Major among these demands is an optimized system design for a dual field of view (FOV); a wide FOV for search mode and a narrow FOV for targeting. The F#, thus, should change with the mode of operation. However, if the F# is changed without changing the effective cold stop diameter of the FPA, the cold shield efficiency is reduced resulting in unacceptable amount of noise. Work is going on, on various methods to vary the cold shield diameter. Another demand is the requirement for a focus free optical system with a large depth of field. In a traditional night vision system there are two methods which allow the user to see both distant and close objects clearly. One involves adaptively changing the focus and the other involves stepping down the aperture. Efforts are being done in the direction to achieve imaging lens with extended depth of focus without reducing the aperture or changing the focal length [30].

Summary

Enormous work is going on worldwide to improve upon IRFPA sensors to meet the present needs of thermal imagers which require higher resolution, quicker response time, multispectral imaging and lesser cooling requirements with increased reliability. The efforts are on in many directions which include new material developments for the detectors, for example type II superlattice structures; new device architectures both for detectors and ROIC and also improvement in optical systems to produce improved performance of the thermal imager. At present HgCdTe appears to be dominating the scene for advanced multi-spectral IRFPA applications with a little challenge from QWIP detectors. However, type-II strained layer super-lattice structures may replace HgCdTe for multi-spectral applications in long term. For broad band hyper-spectral applications again there is no challenge to HgCdTe at present.

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