

INFRA RED DETECTORS

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Abstract Infrared radiations are radiations below (infra) visible spectrum. This emergent dual use technology field is fast emerging amongst the most ubiquitous ones. It spans from low-end automatic supermarket door openers to high-end space based detectors used to detect nuclear tests, missiles and intra galactic radiations. At the heart of this technology is the IR detector.

Objective of this report is to review infrared (IR) detectors. Evolution of IR technology has been largely synonymous to advances in IR detectors. Various types of detectors, formats and materials interlaced with their applications have been studied. Fundamentals of IR detectors along with emerging technologies like uncooled microbolometer detector arrays, focal planar arrays, third generation detectors and future trends have also been discussed.

1. INTRODUCTION

Infrared (IR) detectors have been called *the eyes of the digital battlefield*. Military applications in Western countries have spearheaded and dominated the requirements in this field akin to many other emerging fields. In addition to many military applications for IR systems such as target acquisition, search and track, missile seeker guidance, there is a great potential for IR systems in the commercial market. IR systems enhance automobile and aircraft safety, medical diagnosis, and manufacturing quality and control. Industry is looking to expand into the commercial market because the military market is decreasing and concurrently becoming more specialized. Today, only about 20% of the market is commercial. After a decade the commercial market is estimated to grow by over 70% in volume and 40% in value [1].

Ever since astronomer Sir William Herschel in April 1800, announced the discovery of, what we now call, infra red (IR) portion of spectrum, development of IR engineering progressed in tandem with IR detectors. He experimented with a thermometer as a detector to measure the distribution of energy in sunlight. Following the works of Kirchhoff, Stefan, Boltzmann, Wien, and Rayleigh, Max Planck culminated the effort with well-known Planck's law. Though earliest applications of IR dealt with detection of IR radiation, later applications matured to newer detectors and their exploitation by forming IR arrays.

The IR detectors evolved initially with theories and subsequently by improvement of materials. During the first half of nineteenth century, efforts were made to improve the speed and accuracy of only known IR detector, the thermometer. In 1829 Nobilotti made the first thermocouple. Melloni utilized this for making a thermopile capable of detecting heat emission from a human at 30 feet. During 1880's Langly developed a sensitive bolometer that could sense a cow at a quarter of mile. Triad of these three instruments marked the development of IR detectors in nineteenth century. These detectors were sensitive to all infrared wavelengths and operated at room temperature. They had low sensitivity and slow response. Smith discovered photoconductive effect in 1873.

2. MODERN HISTORY

Modern history of IR detectors commenced with development of first IR detector by Case in 1917. He discovered that a substance made of thallium and sulphur exhibited photoconductivity. Later he found that addition of oxygen enhanced the response. However, it had problems of noise and stability. World War II stirred further research in detectors. In 1940's Photon detectors were developed to improve sensitivity and response time. Lead sulfide (PbS) was the first practical IR detector. PbS is sensitive to infrared wavelengths up to $3\mu\text{m}$. IR frequencies are in millions of Hertz; hence, it is easier to express waves in microns. This detector was deployed in a variety of application in the World War II [7].

Beginning in the late 1940's and continuing into 1950's, a wide variety of new materials were developed for IR sensing. Lead Selenide (PbSe) and lead telluride (PbTe), extended the spectral range beyond that of PbS, providing sensitivity in the $3\text{-}5\mu\text{m}$ medium wavelength (MWIR) atmospheric window. Initially, interest centered in $3\text{-}5\mu\text{m}$ and then $8\text{-}14\mu\text{m}$ atmospheric windows though in recent years there has been an increasing interest in longer wavelengths stimulated by space applications. Detector search in US was concentrated in, early 1940's, on Thallus Sulfide, which was later, dropped in favour of PbS, which had longer spectral response and higher performance. The Lead salt detectors were primarily used for anti-aircraft missiles.

The extrinsic photoconductive (PC) response from copper, zinc and gold impurity levels in germanium made devices possible in the $8\text{-}14\mu\text{m}$ long wavelength (LWIR) spectral window and beyond to very long wavelength (VLWIR) region. The end of the 1950's saw the first introduction of semiconductor alloys, in the chemical table group III-V, IV-VI, and II-VI material systems. One such material was indium antimonide (InSb). It had advantages of small energy gap and it could be prepared in a single crystal form. These alloys allowed the bandgap of the semiconductor, and hence its spectral response, to be custom tailored for specific applications. In 1959, Lawson and coworkers composed Mercury Cadmium Telluride or MCT (HgCdTe), a group II-VI material. Due to the tunable band gap property of this three element compound (ternary) utility in the whole IR range became possible. This has today become center of a major industry with a worldwide turnover of billions of dollars.

Initial difficulties in producing high-uniformity MCT resulted in problems related to the uniformity between detector elements. These problems drove designers to use a single-element IR detector. In this case, the scenery image was reconstructed by a serial scanning scheme in which a high-speed horizontal scanning mirror and a slow-moving vertical scanning mirror produced a video image at a full-frame rate. These images suffered from high noise resulting from poor detector performance and a very short integration time (which in turn is a result of the short dwell time). Infrared systems of this type are considered to be *pre-first generation*.

As photolithography became available in the early 1960's it was applied to make IR sensor arrays. Linear array technology was first demonstrated in PbS, PbSe, and InSb detectors. Photovoltaic (PV) detector development began with the availability of single crystal InSb material. In the late 1960's and early 1970's, *first generation linear arrays* of intrinsic MCT photoconductive detectors were developed. These allowed long wave IR (LWIR) forward looking imaging radiometer (FLIR) systems. Although Hg doped germanium with a 0.09 eV actuation energy was a good match to LWIR spectral window, because the detection mechanism was based on an extrinsic excitation, it required cooling power consumption. The 1970's witnessed a mushrooming of IR applications combined with the start of high volume production of first generation intrinsic MCT sensor systems using linear arrays.

At the same time, other significant detector technology developments were taking place. Silicon technology spawned novel platinum silicide (PtSi) detector devices, which was utilized in standard commercial products for a variety of MWIR high-resolution applications.

As MCT technology was further developed, linear arrays of 60, 120, 180, and 240 elements were produced with acceptable uniformity. These systems are in use now for most tactical applications. To reconstruct a video image from these low-dimension detector arrays, a polygon or rotating mirror is often used to scan the horizontal axis. In the vertical axis, an interlaced mirror that doubles the video lines, along with an electronic line-filling scheme, creates a standard video image. The horizontal resolution of first-generation systems was compatible with TV standards, whereas the vertical resolution was low as a result of the low number of elements in the focal-plane array. In addition, because of the short dwell time during scanning, the integration time was short, giving rise to a low sensitivity and hence low image contrast scanning arrays.

Invention of charge coupled devices (CCD) made it possible to have more sophisticated readout schemes. This coupled with advances in silicon chip technology helped development of *second-generation detector* formats containing larger number of detectors. By late 1980s, MCT detectors as large as 480 x 4 elements were developed for use in the long-wavelength IR (LWIR). At the same time, staring arrays medium-format 320 x 240-element two-dimensional (2-D) arrays were developed for medium wavelength IR (MWIR) that was made either of MCT or of indium antimonide.

Second-generation systems became an industry standard in the mid-1990s; it seemed at that time that there was little hurry to develop a newer generation of IR detectors [6]. Post Gulf War lessons made the US military to raise the bars for *third generation systems*.

3. IR FUNDAMENTALS

IR radiations are electromagnetic (EM) waves where wavelengths are larger than those of red light. IR radiation occurs between 0.75 μm to 1000 μm . Various authors have published different proposals of division of IR range. The division shown below (Table1) is based on Hudson [9]. 1 μm is sensitivity limit of popular Si detectors. Similarly, wavelength 3 μm is sensitivity of PbS and InGaAs detectors. 6 μm is sensitivity limit of InSb, PbSe, PtSi detectors and MCT detectors are optimised for 3–5 μm atmospheric window; and finally wavelength 15 μm is a long wavelength sensitivity limit of HgCdTe detectors optimised for 8–14 μm atmospheric window.

Table 1. Division of infrared radiation.

Region (abbreviation)	Wavelength range (μm)
Near infrared (NIR)	0.78–1
Short wavelength IR (SWIR)	1–3
Medium wavelength IR (MWIR)	3–6
Long wavelength IR (LWIR)	6–15
Very long wavelength IR (VLWIR)	15–1000

3.1 Thermal emission

Thermal emission emerges from every body above absolute zero temperature in the form of EM waves; likewise every body also absorbs part of EM waves, which falls on it. If the radiation that falls on a body, fraction r is reflected, a is absorbed and t is transmitted. Hence,

$$r + a + t = 1$$

Though all three terms are independent of wavelength they do vary with it. For example snow has a high reflectance(r) and very low absorptance (a) in visible light. It has very low reflectance and absorptance approaching unity at about 10 microns. Thus, if our eyes could respond to this wavelength, snow would appear black.

The ideal radiator is a black body, which can absorb the entire radiation that falls on it. For such a body absorptance equals one. At a given wavelength the ratio of infrared energy radiated by an object at a given temperature to that emitted by a blackbody at the same temperature is termed as emissivity. The emissivity of a blackbody is unity at all wavelengths.

All objects are composed of continually vibrating atoms, with higher energy atoms vibrating more frequently. The vibration of all charged particles, including these atoms, generates electromagnetic waves. Higher the temperature of an object, faster the vibration, and thus higher the spectral radiant energy denoted by Kirchoff as $W(\lambda)$ or spectral radiant emittance. Hence, all objects are continually emitting radiation at a rate with a wavelength distribution that depends upon the temperature of the object and its spectral radiant emittance. The radiative power (or number of photons emitted) and wavelength distribution are given by Planck's radiation law given below

$$W(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \left[\exp\left(\frac{hc}{\lambda kT}\right) - 1 \right]^{-1} \quad \text{W/(cm}^2 \mu\text{m)},$$

$$P(\lambda, T) = \frac{2\pi c}{\lambda^4} \left[\exp\left(\frac{hc}{\lambda kT}\right) - 1 \right]^{-1} \quad \text{photons/(s cm}^2 \mu\text{m)},$$

where, the equations relate wavelength(λ), temperature(T), Planck's constant (h), the velocity of light(c), and the Boltzmann's constant (k).

Planck's curves for a number of blackbody temperatures are plotted in Fig.1. As the temperature increases, the amount of energy (i.e. area under the curve) emitted at any wavelength increases while the wavelength of peak emission decreases. Wien's displacement law gives the later

$$\lambda_{mw}T = 2898 \mu\text{mK} \quad \text{for maximum watts,}$$

$$\lambda_{mp}T = 3670 \mu\text{mK} \quad \text{for maximum photons.}$$

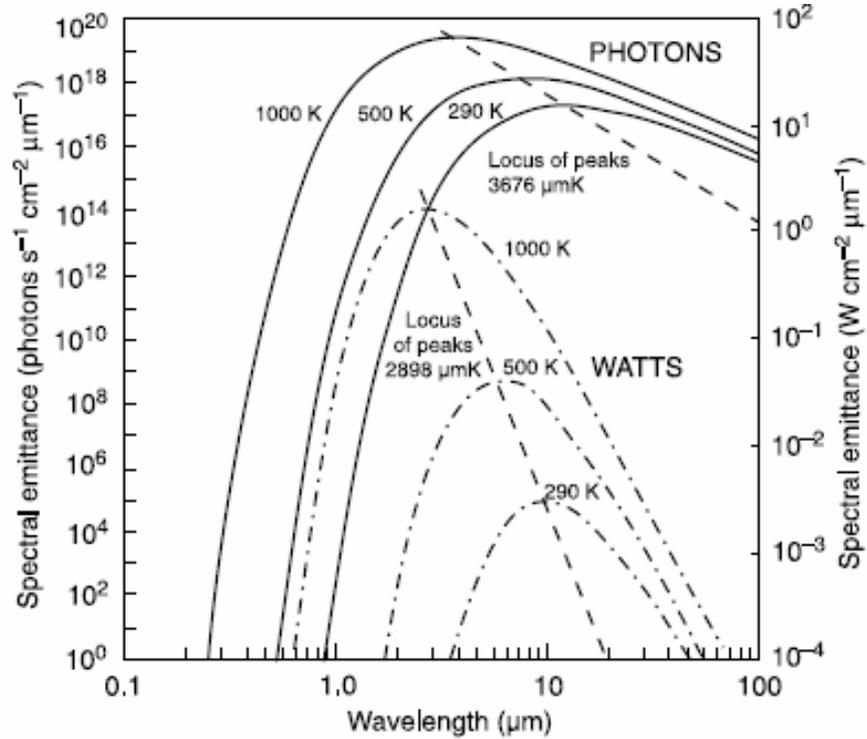


Fig1. Planck's law for spectral emittance

It is inferred from the figure that lower temperature require measurement to longer wavelengths. Also, for 1000K and 500K curves vertical distance between the curves is greater at short wavelengths (2 μ m) than longer wavelengths (12 μ m). This means radiation changes much more for a given temperature change at shorter wavelengths, making detectors that operate at such wavelengths more sensitive.

3.2 Atmospheric transmission

Atmospheric transmission is a must for all IR applications on earth.. IR applications require radiation transmission through air, but the processes of scattering and absorption attenuates the radiation. Scattering causes a change in the direction of a radiation beam; it is caused by absorption and subsequent reradiation of energy by suspended particles. For larger particles, scattering is independent of wavelength. Scattering by gas molecules is negligibly small for wavelengths longer than 2 μ m. Also, smoke and light mist particles are usually small with respect to IR wavelengths, and IR radiation can therefore penetrate further through smoke and mists than visible radiation. However, rain, fog particles and aerosols are larger and consequently scatter IR and visible radiation. Fig. 2 is a plot of the transmission through 6000 ft of air as a function of wavelength. Specific absorption bands of water, carbon dioxide and oxygen molecules are indicated which restricts atmospheric transmission to two windows at 3–5 μ m and 8–14 μ m. Ozone, nitrous oxide, carbon monoxide and methane do absorb radiation but are less important IR absorbing constituents of the atmosphere.

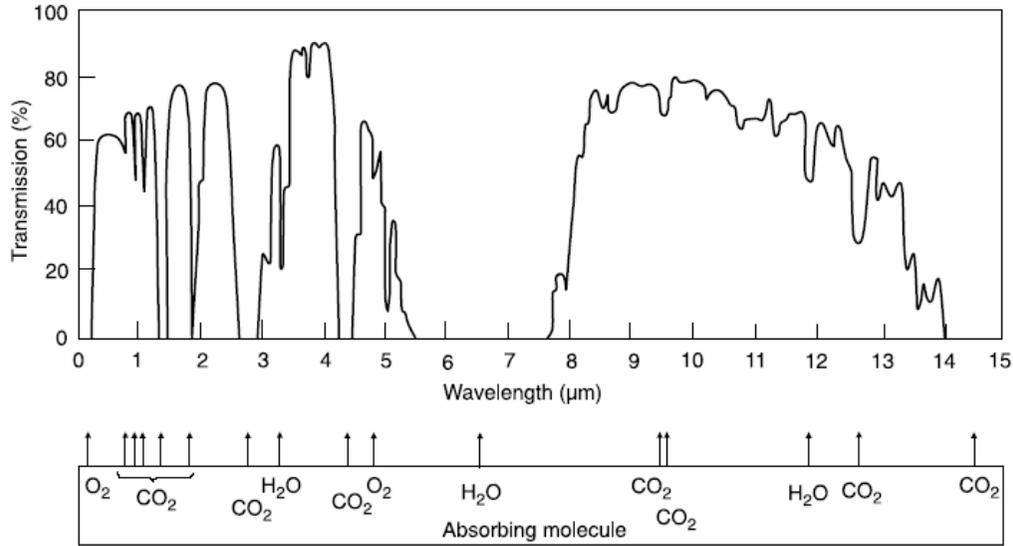


Fig.2 Transmission of IR in atmosphere

3.3 Scene radiation and contrasts

Radiation received from any object is the sum of the emitted, reflected and transmitted radiation. Objects that are not blackbodies i.e. greybodies emit only the fraction of blackbody radiation, and remaining fraction is either transmitted or, for opaque objects, reflected. When the scene is composed of objects and backgrounds of similar temperatures, reflected radiation tends to reduce the available contrast. However, reflections of hotter or colder objects have a significant effect on the appearance of a thermal scene. The powers of 290 K blackbody emission and ground-level solar radiation in MWIR and LWIR bands are given in Table 2. We can see that while reflected sunlight has negligible effect on 8–13 μm imaging, it is important in the 3–5 μm band. Thermal image arises from temperature variations or differences in emissivity within a scene. The thermal contrast (C) is one of the important parameters for IR imaging devices. It is the ratio of the derivative of spectral photon incidence to the spectral photon incidence

$$C = \frac{\partial W / \partial T}{W}$$

Table 2 Power available in each MWIR and LWIR band [3]

IR region (μm)	Ground-level solar radiation (W/m ²)	Emission from 290 K blackbody (W/m ²)
3–5	24	4.1
8–13	1.5	127

The contrast in a thermal image is small when compared with visible image contrast due to differences in reflectance. For a 291 K object in a 290 K scene, it is about 0.039 in the 3–5 μm band and 0.017 in the 8–13 μm band. Thus, while LWIR band may have the higher responsivity i.e. higher ratio of signal output to incident radiant flux, MWIR band has greater contrast.

3.4 Choice of IR band

In the spectral range of 0.78 - 3.0 μm , IR detectors are used for applications as diverse as fiber optic communications, agricultural sorting, environmental monitoring, and chemical analysis. Further into the IR region (from 2 - 5 μm), applications for IR detectors include non-contact temperature sensing, thermal imaging, and gas analysis for pollution control. The 3–5 μm band is more appropriate for hotter objects, or if sensitivity is less important than contrast. It has advantages of lower ambient and background noise. The LWIR (8-15 μm) corresponds to a peak for thermal emission at ambient temperature and better transmission through mist and smoke. These ranges also have high transmission through the atmosphere. This spectral region is thus optimal for such applications as thermal imaging, non-contact temperature sensing, security sensing, and environmental monitoring. Photoconductive MCT detectors provide best performance at these wavelengths.

The advantage of MWIR band is smaller diameter of the optics required to obtain a certain resolution and that some detectors may operate at higher temperatures (thermoelectric cooling) than it is usual in the LWIR band where cryogenic cooling is required (about 77 K). MWIR and LWIR spectral bands differ substantially with respect to background flux, scene characteristics, temperature contrast, and atmospheric transmission under diverse weather conditions. Factors which favour MWIR applications are higher contrast, superior clear-weather performance (favorable weather conditions, e.g., in most countries of Asia and Africa), higher transmittivity in high humidity, and higher resolution due to ~ 3 times smaller optical diffraction. Factors that favour LWIR applications are better performance in fog and dust conditions, winter haze (typical weather conditions, e.g., in West Europe, North USA, Canada), higher immunity to atmospheric turbulence, and reduced sensitivity to solar glints and fire flares. The far infrared (FIR) range generally refers to the electromagnetic band from 30-1000 μm and is the source of much of the astrophysics information.

4. IR DETECTOR FUNDAMENTALS

Infrared detectors are transducers of radiant energy. Since infrared radiations do not rely on visible light, they offer possibility of seeing in the dark or through obscured conditions, by detecting the infrared energy emitted by objects. The detected energy is translated into imagery showing the energy differences between objects. Hot objects such as people stand out from the typically cooler backgrounds (Fig.4) regardless of the available visible light. Under infrared light, the world reveals features not apparent under regular visible light. People and animals are easily seen in total darkness, weaknesses are revealed in structures, components close to failure glow brighter, visibility is improved in adverse condition such as smoke or fog.



Fig.4 Person's IR image in night

There are two fundamental IR detectors, photon and thermal detectors. Classification of detectors is placed in Fig. 4.1 below. Thermal detectors respond to temperature changes generated from incident IR radiation through changes in physical and electrical properties. Photon detectors generate free electrical carriers through interaction of photons and bound electrons. *Four main types of photodetectors* are intrinsic (PV, PC) extrinsic, photoemissive and newer QWIP's. Thermal detectors can be classified as thermometers, thermocouples, thermopiles, bolometers and newer microbolometers and microcantilevers. They are explained below.

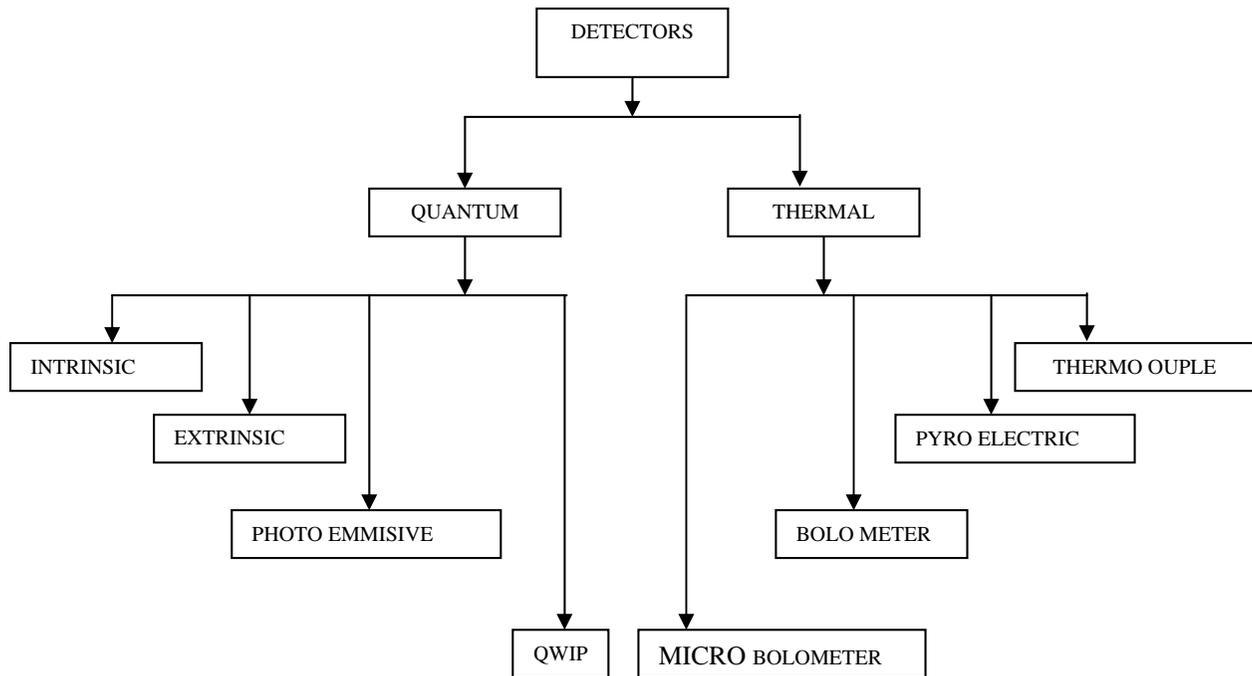


Fig. 4.1 Classification of detectors

4.1 Photon detectors

Photon detectors convert photons directly into free current carriers by photoexciting electrons across the energy bandgap of the semiconductor to the conduction band. This produces a current, voltage or resistance change of the detectors. The photoexcitation is caused by the radiation interacting directly with the lattice sites. Therefore, the temperature of the detector must be low enough so that the number of carriers thermally excited across the bandgap is less significant. To maintain a low temperature, the cooling system or the Dewar (thermos bottle) is required, which increases the system cost. Generally, the sensitivity of photon detectors depends on the spectral absorption and photoexcitation. The spectral response of photon detectors depends on the energy. In the thermal detectors, the incident radiation absorbed by the crystal lattice leads to a temperature change that changes the physical or electrical property of the detectors. The following are examples of photon detectors.

4.1.1 Photovoltaic intrinsic detectors

Photovoltaic intrinsic detectors structure is based on a P-N junction device as shown in Fig. 4.2(a). The reflective coating on the bottom of the detector provides the double chances (injection and reflection) of photon absorption. Under IR radiation, the potential barrier of the P-N junction

leads to the photovoltaic effect. An incident photon with the energy greater than the energy band gap of the junction generates electron-hole pairs and the photocurrent is excited. The resultant curve of the PV detector when exposed to IR radiation is similar to that of normal P-N junction device but shifted downward as shown in Fig. 4(b). The amount of the photon-excited current is denoted by photocurrent. PV devices operate in the diode's reverse bias region; this minimizes the current flow through the device that in turn minimizes power dissipation. In addition, PV detectors are low noise because the reverse bias diode junction is depleted of minority carriers. The highest performance PV detectors are fabricated from Si, Ge, GaAs, InSb, GaAs and MCT.

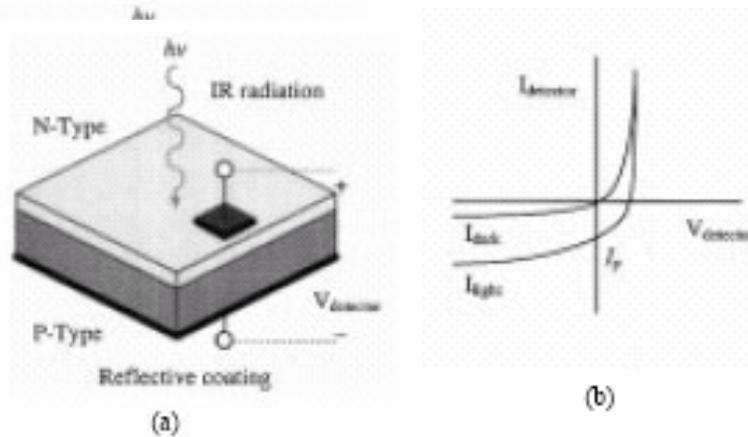


Fig.4.2 (a) Structure of photovoltaic detector Fig. 4.2(b) V-I curve of photovoltaic detector

4.1.2 Photoconductive intrinsic detectors

Photoconductive intrinsic detectors mechanism is to produce the conductance change under the IR radiation. In PC detectors, the free carriers generated by the photon energy cause increase of the conductance of photoconductive material under an applied constant electric field. The structure of PC detectors is shown in Fig. 4.2 (c).

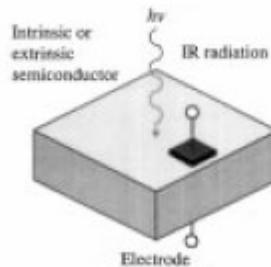


Fig. 4.2(c) Photo conductive detector

The detector material can be either an intrinsic or an extrinsic semiconductor. The spectral response of a semiconductor material can be controlled by the doping of the intrinsic semiconductor to make PC detectors applicable in LWIR detection. In the case of intrinsic semiconductor, the incident IR radiation is absorbed to generate holes and electrons. In the case of extrinsic semiconductors, the photon energy is absorbed by the impurity, and only the majority carriers are excited. Under the applied constant bias, the resultant current level is proportional to the incident photon flux. In PC detectors, the photoconductive gain is defined as the ratio of carrier lifetime to detector transit time. The gain usually varies from 0.5 to greater than unity. If carrier lifetime is longer than transit time, the free carriers can transit across the detector without recombination and the current gain is greater than one. Since the current flows under a constant electric field, the photoconductive detector consumes power and generates heat. This makes it unsuitable for large IR

array applications. Moreover, an additional noise source called the generation recombination noise exists in PC detectors besides the thermal and the noise sources.

4.1.3 Advantages of PV detectors over PC detectors

Advantages of PV detectors over PC detectors include a better signal to noise ratio simpler biasing and better responsivity. PV detectors are more fragile, susceptible to electrostatic discharge and to physical damage due to handling. Practically PV detectors are made of Si, InSb, and HgCdTe. PC detectors include doped Ge and Si detectors the ternary compounds HgCdTe and PbSnTe can be used for PC detectors as well as PV detectors. Some comparisons between photon detectors and thermal detectors are summarized below.

Table 4 Comparison of Photon and Thermal detectors

Parameter	Photon Detector	Thermal Detector
Response time	Fast	Slow
Spectral responsively	Narrow and selective	Wide and flat
Sensitivity	High	Low
Operating temperature	Cryogenic	Room
Cost	Expensive	Economical
System requirement	Cooling System	Optical Chopper

4.1.4 Extrinsic detectors

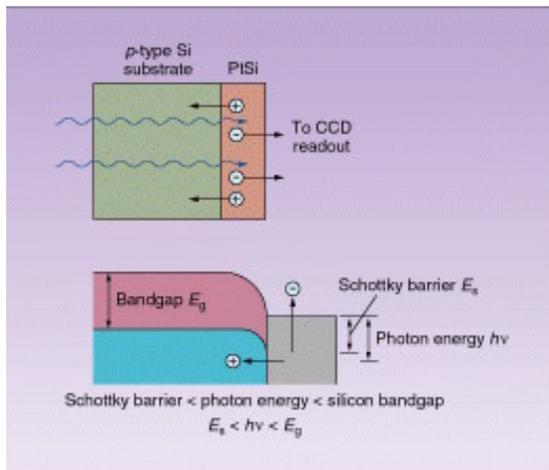
Extrinsic detectors are based on Si (Si: X) or Ge (Ge: X) doped with impurities such as Boron, Arsenic and Gallium. They are similar to intrinsic detectors. However, in extrinsic detectors carriers are excited from the impurity levels and not over the bandgap of the basic material. Both photovoltaic and photoconductive types exist. They have the advantage of being able to operate at much lower wavelengths than both intrinsic silicon and MCT. To overcome problems of positive holes left behind in valence band higher doping density are required.

4.1.5 Photo-emissive detectors

To avoid the extreme cooling demands of extrinsic semiconductor detectors and in some cases to reach even longer wavelengths, there is a third approach i.e. photoemissive detectors, or free-carrier or Schottky-barrier detectors. In these detectors, a metallic compound, for example, platinum silicide (PtSi), is overlaid by doped silicon. A photon bounces an electron or, in this example, a hole, out of the conductor into the silicon (Fig 4.1 d). The advantage of such devices is that response does not depend on the characteristics of the semiconductor but on those of the metal, which are extremely uniform, so that high uniformity of response is much easier to achieve. However, absorption is proportional to the square of the wavelength, so for wavelengths of a few microns, efficiency and sensitivity are much less than for extrinsic devices. At very long wavelengths, beyond 100 μm , these detector types are quite useful.

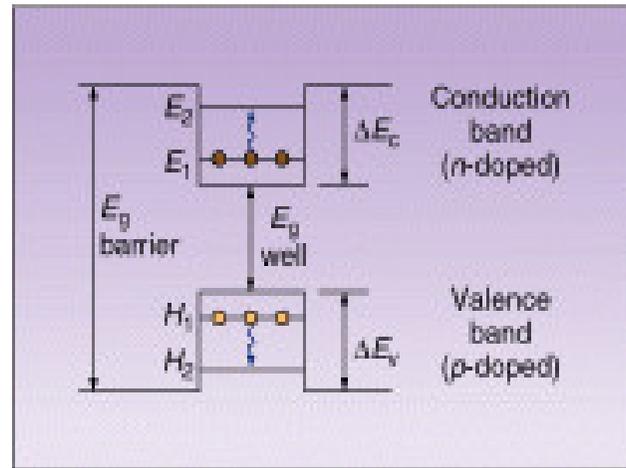
4.1.6 Quantum Well Infrared Photo detector

The fourth main type of IR detector is the quantum-well IR photoconductor (QWIP). The operating principle in these devices is similar to that for extrinsic detectors. The dopants are used to alter the band structure. But in QWIPs, the dopants are concentrated into microscopic regions, creating quantum wells, where the band structure has shifted. Detection occurs when a photon knocks an electron or hole out of the quantum well into the neighboring band (see Fig. 2). As with extrinsic semiconductor detectors, QWIPs can be tailored to reduce the energy a photon needs for detection. But QWIPs are much more sensitive than extrinsic types, because the entire quantum well, not just an individual dopant atom, acts as an absorber. Because the quantum wells are 10-100 atoms across, their effective absorption area is much higher.



6-FEA-1 Fig. 1

Fig. 4.1(d) Photoemissive detector



6-FEA-1 Fig. 2

Fig. 4.1(e) QWIP detector

Currently, this technology is relatively unproven and immature due to long-term instability and non uniformity of these materials. Another drawback is the requirement for cooling the detector to ~ 65 K (-208°C), which puts an added load on the cooling device, say, inside a camera. Assuming that the technical concerns can be addressed, QWIP could benefit the user by providing a camera with very good imaging and measurement performance while operating in the long-wavelength region. These units could be useful in outdoor applications for which solar reflections are problems or in applications for which very low ambient temperatures are a factor. One of examples is tracking aerial targets.

5. THERMAL DETECTORS

The absorption of IR energy heats the detection element in energy or thermal detectors, leading to changes in physical properties which can be detected by external instrumentation Thermal detectors are operated at room temperature and have a wide spectral response. Since the operation of thermal detectors involves a change in temperature, they have an inherently slow response and a relatively low sensitivity compared to photon detectors. The response time and sensitivity of thermal detectors are influenced by the heat capacity of detector structure as well as the optical radiation wavelength. In some applications of thermal detectors, an optical chopper is also needed. The following are examples of energy detectors.

5.1 Thermocouples / Thermopiles

Thermocouples / Thermopiles are formed by joining two dissimilar metals that create a voltage at their junction forms thermocouples. This voltage is proportional to the temperature of the junction. When a scene is optically focused onto a thermocouple detector, its temperature increases or decreases as the incident IR flux increases or decreases. The change in IR flux emitted by the scene can be detected by monitoring the voltage generated by the thermocouple. For sensitive detection, the thermocouple must be thermally insulated from its surroundings. For fast response, the thermocouple must be able to quickly release built up heat. This tradeoff between sensitivity of detection and the ability to respond to quickly changing scenes is inherent to all energy detectors. A thermopile is a series of thermocouples connected together to provide increased responsivity.

5.2 Pyroelectric detectors

Pyroelectric detectors consist of a polarized material which, when subjected to changes in temperature, changes polarization. These detectors operate in a chopped system; the fluctuation in the exposure to the scene generates a corresponding fluctuation in polarization and thus an alternating current that can be monitored with an external amplifier. Similar to pyroelectric detectors, ferroelectric detectors are based on a polarized material which, when subjected to changes in temperature, changes polarization. They have the advantage of large dynamic range covering power ranges from 10nW to 10W.

5.3 Thermistors / Bolometers

In thermistors, the resistance of the elements varies with temperature. One example of a thermistor is a bolometer. Bolometers function in one of two ways: monitoring voltage with constant current or monitoring current with constant voltage. Advances in the micromachining of silicon have led to the exciting field of *microbolometers* have led to measurable changes of .1centigrade from a power input of 10 nW. A microbolometer consists of an array of bolometers fabricated directly onto a silicon readout circuit. This technology has demonstrated excellent imagery in the IR. Although the performance of microbolometers currently falls short of that of photon detectors, development is underway to close the performance gap. Microbolometers can operate near room temperature and therefore do not need vacuum evacuated, cryogenically cooled dewars. This advantage brings with it the possibility of producing low cost night vision systems for both military and commercial markets.

5.4 Microcantilevers

Microcantilevers are based on the bimetal effect to measure IR radiation. This effect utilizes the difference in thermal expansion coefficients of two different bimetals to cause a displacement in a microcantilever. In combination with a reference plate, this cantilever forms a capacitance. When infrared light is absorbed by the microcantilever, the microcantilever deflects and thus alters the capacitance of the structure. This change in capacitance is a measure for the incident infrared radiation.

6. COOLED AND UNCOOLED DETECTORS

6.1 Requirement of cooling

The signal output of a photon detector is so small that at ordinary temperatures it is swamped by the thermal noise due to random generation and recombination of carriers in the semiconductor. In order to reduce the thermal generation of carriers and minimise noise, photon detectors must be cooled and must therefore be encapsulated. Most detectors are cooled, either because they do not operate at room temperature or because they operate much better when cooled. Cooling mechanism is either a cryogen or refrigerant. The detector is usually mounted in a vacuum tight enclosure that serves twin purposes of avoiding condensation on detector and prevents cryogen from boiling off too rapidly.

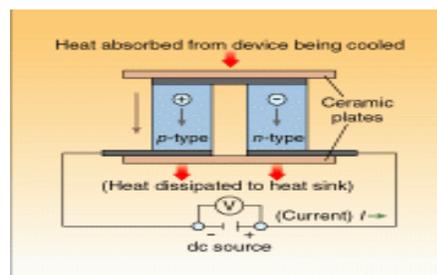
6.2 Types of cooling systems

Various types of cooling systems are used for cooling IR detectors. *Dewars*, the technical name for vacuum bottle, are named after the inventor. They range in sizes from a few inches to large diameter test chambers. *Refrigerators* may be of closed cycle type, which recycle same fluid over and over and open cycle type, which draws gas from high-pressure tanks and vents to atmosphere after use. *Radiation coolers* are used in space. They face the sky and radiate energy away into space. They require no moving parts and no operating fluid except that required to point them away from sun. *Thermoelectric coolers* provide cooling by forcing currents through a junction of dissimilar metals. These coolers are simple reliable, small noiseless and high life. Their primary disadvantage is high power requirement.

Application of cooling systems in LWIR spectral regions requires operating temperatures of 100 K or less, which can be attained only by liquid-nitrogen-filled Dewars or closed-cycle refrigerators. But for many applications at near-IR and mid-IR wavelengths, thermoelectric cooling is gaining ground. One of the main advantages of TE coolers compared to bulk liquid nitrogen or mechanical refrigerators is their small size, which allows the detector and cooler to be incorporated in a single housing.

6.3 Thermoelectric (TE) coolers

Thermoelectric (TE) coolers are simply low-power, miniature heat pumps that are small enough to be easily integrated into compact optical systems. When properly packaged, TE coolers efficiently cool small detector chips (3 x 3 mm) to temperatures below -70°C. Thermoelectric coolers provide temperature control to better than 0.1°C, ensuring stable detector performance. The devices operate under direct current (dc), minimizing electrical noise, and can be used for heating or cooling by reversing the direction of current flow. Because both the detector and cooler are solid-state components, operating lifetimes are greater than 10 years.



3-DH-2 97 Fig. 1

Fig. 6.1 TE Cooler

A single-stage TE cooler (Fig. 6.1) consists of a matrix of thermoelectric couples connected electrically in series, and thermally in parallel. The couples themselves consist of bismuth telluride p-type and n-type semiconductor material. Depending on performance requirements, a TE cooler incorporates anywhere from one to several hundred couples. These couples are sandwiched between ceramic plates, which provide structural integrity as well as electrical insulation between the heat sink and the object being cooled.

When a positive dc voltage is applied to the n-type material, electrons pass from the p- to the n-type material. The temperature on the cold side decreases because heat is being absorbed from it. This heat pumped from the cold side plus the heat generated by the input power is conducted through to the hot side of the cooler, where it is dissipated by a heat sink. The degree of cooling achieved is proportional to the current and the number of thermoelectric couples. For more extensive cooling requirements, multiple cooler assemblies can be stacked to accommodate additional heat pumping for both active and passive heat loads. Thermoelectric coolers with as many as four stages are typically used in many IR detector applications.

6.4 High operating temperature process

A possible solution called high operating temperature process for decreasing the size of systems using cooled photon detectors or HOT processing is currently more promising. First proposed back in 1985, this approach uses a narrow-gap layer sandwiched between two wider-gap materials in the case of mercury cadmium telluride, or between a wider gap material and a heavily doped layer when using indium antimonide. The structure has a reversed-bias *p-n* junction that extracts the minority charge carriers.

This structure reduces dark current in several ways. First, the wide-gap regions have very low thermal generation rates. They also isolate the active region of the device from carrier generation at the contacts. The device's main advantage, though, is that, by sweeping out the minority carriers, the electrons, it directly reduces the leakage currents.

For years, the noise levels associated with these devices remained too high for imaging applications or for applications requiring room-temperature operation, but recent work at the Defense Research and Evaluation Agency (Malvern, England) and Marconi Infrared Ltd. (Southampton, England) indicates that further reductions in dark currents could lead to practical operation of the devices at 240 K, which is within the reach of thermoelectric coolers. This is not uncooled operation, but it is getting close.

In these devices, internal radiation mechanisms are important. Recombination of holes and electrons produces photons, which are then absorbed in the active region, generating a dark current. To reduce this current, the British researchers used a strange property of the device called negative luminosity, which is a reduction of the emission from a surface below the level needed to maintain thermal equilibrium. In other words, the body becomes blacker than a blackbody at the same temperature.

In equilibrium, the absorption of photons and the production of electron-hole pairs are balanced by electron-hole recombination and photon emission. Since the electrons are swept up so rapidly, though, they do not have time to recombine, and the entire active layer becomes a sink for photons, producing negative luminosity. This process reduces the dark current produced by intrinsic photon production.

6.5 Uncooled IR detectors

With advances in micromachining processes based on silicon processing techniques field of uncooled detectors has come off age. Even until the mid-1990s, sensitivity levels of the highest known uncooled sensitivity detector the bolometer was considered low. At room temperature, a radiation intensity of 1 mW/cm^2 leads, at equilibrium, to an increase in temperature of 1 K. One-tenth of that change in temperature produces easily detectable change in resistance. Since response time is proportional to the thickness of the absorber, with a micro machined bolometer of thickness of about $0.5 \text{ }\mu\text{m}$, response times drop to tens of milliseconds. This is fast enough for normal video camera operation at 30 frames per second. Application areas of this include third generation IR systems.

7. DETECTOR FORMAT AND ARCHITECTURES

IR detectors are available as single element detectors in circular, rectangular, cruciform, and other geometries for reticle systems, as linear arrays, and as two dimensional (2D) focal plane arrays (FPAs). Linear and 2D arrays are fabricated with a variety of device and signal output architectures. In general, the IR FPA can be divided into *two major parts*, namely the detector array (Fig. 7.1) and the readout electronics. As compared to the conventional discrete design, the IR FPA has the inherent *advantages* of high packing density, low cost, reduced signal leads through the dewar, high feasibility on-chip signal processing, and high flexibility for system integration.

First generation linear arrays were usually front side illuminated, with the detector signal output connected by wire bonding to each element in the array. The signal from each element was then brought out of the vacuum package and connected to an individual room temperature preamplifier prior to interfacing with the imaging system display. Gain adjustments were usually made in the preamplifier circuitry. This approach limited first generation linear arrays to less than two hundred elements. Second generation arrays, both linear and two-dimensional are frequently backside illuminated through a transparent substrate.

Staring FPA detectors have high-resolution IR capabilities. An array of detectors staring at the scene rather than a single detector being scanned across the scene means IR cameras can be much smaller, lighter, and more power efficient than a camera with more-elaborate scanning components. Modern infrared FPA systems are aimed to have the portability of video camcorders and the imaging quality of black-and-white TV cameras.

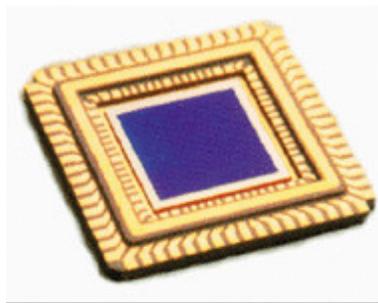


Fig. 7.1 Focal Planar Array of 256x 256 detectors.

Figure of merit for FPA in terms of importance are fill factor and quantum efficiency. All surface of FPA detector is not sensitive to IR energy. Around the rows and columns of individual

IR detectors making up the array is an inactive region surrounding each of the detectors. The inactive areas serve as pathways for electronic signals. The ratio of active IR sensing material to inactive row and column borders is called the *fill factor*. An ideal detector would have a very high fill factor because it would have a large percentage of its area dedicated to collecting IR photons and a very small area dedicated to detector segregation. Today's best infrared FPA detectors offer fill factors as high as ninety percent.

Effect of high fill factor is to provide better sensitivity and overall image quality than one with a lower fill factor. Also, high-fill-factor detectors typically offer better cooling efficiency, so less power is used to cool the detector to operating temperature. This savings translates into longer battery life and greater cooler reliability. *Quantum efficiency* refers to the relative efficiency at which IR photons are collected and converted into electrical charges. High quantum efficiency makes signal processing easier. Surprisingly, the most popular infrared FPA detector material today is platinum silicide (PtSi) that has very low quantum efficiency (less than 1%). Although quantum efficiency is only one measure of a system's design, it is a good way to evaluate overall sensitivity. Infrared FPAs with high quantum efficiency usually offer better sensitivity and performance at low temperatures.

7.1 Commonly Used Structures

Impact of VLSI technologies on the development of IR FPA detector fabrication has made the design of high-sensitivity, high-density, large-format and high-spectral-resolution systems feasible. The application of various developed technologies on the design of IR FPA's has resulted in the advantages of simplified electrical interconnection, reduced signal number leads through the dewar, higher performance reliability, and simplified package. Commonly Used Structures of the three major classes of IR FPA's, namely, hybrid array, monolithic array, and pseudo monolithic array are discussed below.

7.1.1 Hybrid Array

Hybrid Array has the IR sensitive detector material on one layer and the signal transmission and processing circuitry on another layer. The most commonly used IR FPA structures in the hybrid array are flip-chip and Z plane technologies. In the flip chip technology, the two layers are bonded together by small indium bumps, which transmit the signal from each detector element to its respective signal path on the multiplexer below (Fig. 7. 2 a). This is the most used structure in the hybrid array technology.

7.1.2 Z –plane hybrid array

In *Z –plane hybrid array* technology shown in Fig. 7.2(b), the readout chips are stacked one on top of another and then the detector array is mounted to the third-dimensional plate on the edge. In the -plane structure, one readout chip is used by one channel of detectors so that many electrical circuit techniques like complex input circuit, gain offset correction, A/D converter, filter, smart, and neural function, as well as image signal processing stage can be implemented on the readout chip. However, the image resolution is limited by the readout chip thickness. In the application of hybrid array technology, uniformity of indium bumps, chip alignment, as well as thermal expansion effect and mechanical damage on the detectors should be considered during the hybridization process.

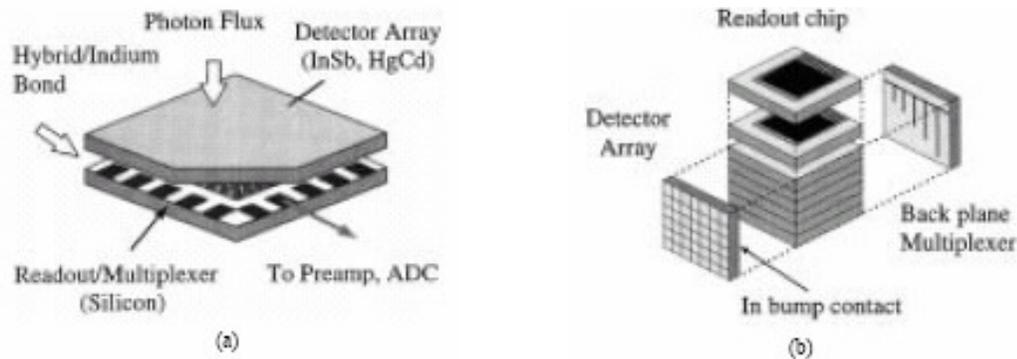


Fig. 7.2 the flip-chip array [5] and the Z-plane array [4].

7.2 Monolithic array technology

Monolithic array technology is currently developed to solve the hybrid process problems of interaction of detectors with silicon readout circuitry. Building IR detectors like PtSi Schottky barriers, micromachined bolometers or extrinsic detectors on the silicon substrate provides solution. Thus, both IR detectors and readout circuits can be fabricated in a monolithic chip as shown in Fig. 7.2 (a). Both production and reliability of IR FPA's can be improved under monolithic design. However, the detector types and materials must be compatible with the silicon process. This limits the applications of the monolithic array on IR image systems.

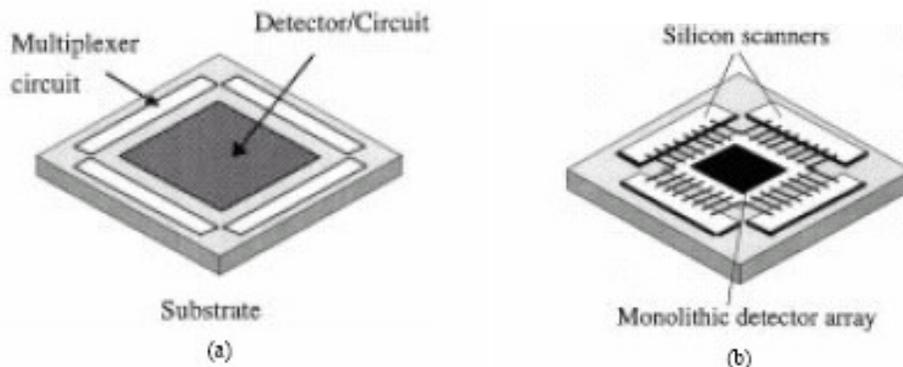


Fig. 7.3 Monolithic arrays

Fig. 7.3 Pseudomonolithic arrays

7.3 Pseudomonolithic Array

As an alternative method to the indium-bumping hybrid array and monolithic array technologies, the readout chip and detector chip can be compounded through the via-hole technique in the so-called pseudomonolithic array as shown in Fig. 7.3(b). Both readout chip surface and detector chip surface must be polished to achieve a precise flatness and parallelism before combining as a single chip. Then some detector fabrication processes and routing metallization processes are applied on the combined single chip. The pseudomonolithic technology retains some of pseudomonolithic array technology advantages of silicon-like processing, but its reliability still needs to be optimized.

7.4 Comparison between hybrid and monolithic array

Comparison between hybrid and monolithic array are bound to be made. Monolithic FPAs are easier and less expensive to manufacture than hybrids because fewer manufacturing steps are required. Conversely, monolithic FPAs generally have lower performance than their hybrid counterparts because having the detector material and signal pathways on the same level results in a

significantly lower fill factor (~55%). Most users see the difference between a system with a monolithic FPA array and a hybrid array manifested in poorer image quality. This difference is particularly noticeable when viewing low temperatures or scenes with small temperature differences.

Although hybrid process requires more steps and can be more expensive, it results in FPAs with a significantly higher fill factor (~75%-90%). The higher fill factor resulting from this geometry provides much higher sensitivity than usually found in corresponding monolithic FPAs. The greatest benefit results from the high thermal sensitivity because of the hybrid FPA's relatively high fill factor. Some hybrid FPA cameras provide sensitivity down to 0.02°C. Very high sensitivity can be useful in nondestructive-test applications, air in-leakage surveys, and building diagnostic studies.

8. MATERIALS IN IR DETECTOR FORMATS

Differences in materials and their compositions have profound effect on behaviour of material as an IR detector. IR detectors are static sensitive, fragile and environmental sensitive. Hence they should be handled with caution. Various materials are used for detection. Silicon, gallium arsenide, MCT and lead salts are amongst most used [8]. Materials typically used are shown below in Table 5.

Table 5 Materials used in IR detectors

Photon Detectors		Energy Detectors	
Intrinsic, PV	- MCT	Bolometers	- Vanadium Oxide (V ₂ O ₅)
	- Si, Ge		- Poly-SiGe
	- InGaAs		- Poly-Si
	- InSb, InAsSb		- Amorph Si
Intrinsic, PC	- MCT	Thermopiles	- Bi/Sb
	- PbS, PbSe	Pyroelectric	- Lithium Tantalite (LiTa)
Extrinsic	- SiX		- Lead Zirconium Titanite (PbZT)
Photo-emissive	- PtSi	Ferro-electric	- Barium Strontium Titanite (BST)
QWIP	- GaAs/AlGaAs	Micro cantilever	- Bimetals

8.1 Silicon and Germanium detectors

Silicon and Germanium detectors have inherent advantages of manufacturing due to compatibility with semiconductor production techniques. The use in IR detector stems from variations possible due to doping. In case of silicon doping with gold gives it an energy band gap of 0.02 eV and cut off wavelength of 5µm. These figures get altered to 0.05 eV and ~20µm with phosphorus doping. Similarly the quantum efficiency, electric field and thickness can be varied from 20% to 40%, 100 to 500V/cm and 1 to 3 respectively. Doping silicon with boron, arsenic, or gallium, for example, introduces different energy levels into the host-material bandgap. Electrons can then be knocked off the dopants at energy levels well below the cutoff wavelengths for silicon or germanium, and IR detection at longer wavelengths becomes possible.

8.2 MCT detectors

MCT detectors have been the most important semiconductor for mid and long-wavelength (3-30 μm) infrared photodetectors. No single known material surpasses MCT in fundamental performance and flexibility. MCT ($\text{Hg}_{1-x}\text{Cd}_x\text{Te}$) is a combination of mercury telluride and cadmium telluride. Relative concentrations of two molecules i.e. x and $1-x$ are deliberately adjusted in growth process to obtain desired mixture. This helps to adjust cut off wavelength (maximum wavelength of response). Hence, MCT exhibits extreme flexibility. It can be tailored for optimized detection at any region of the IR spectrum (Table 4). Both PC and PV types are available. Limitations of MCT are compositional nonuniformity, difficulty to grow on silicon and fragility. For high-performance applications such as thermal imaging and radiometry, photoconductive, MCT provides better sensitivity, faster response, and lower bias voltage [4]. Three-stage or even four-stage cooling is used for maximum performance.

Table 4 Tailoring MCT wavelengths

x	0K(μ)	100K(μ)	200K(μ)	300K(μ)
.4	3.5	3	3	3
.22	13	10	9	7
.18	>50	25	13	10

8.3 Indium antimonide

Indium antimonide detectors are most commonly used III-V material, which provide high-performance detector in the wavelength region from 2 to 5 μm . Unfortunately, InSb detectors have to be cooled to liquid-nitrogen temperature. Indium antimonide (InSb) is a detector material that was very common in single-detector, mechanically scanned units. It is a highly versatile detector, which can be used for PC, PV, cooled and uncooled formats thereby justifying the economics of using it. The material typically offers higher sensitivity as a result of its very high quantum efficiency (80%-90%). However, high quantum efficiency is not the most important factor.

With InSb, the detectors swamp in a few microseconds, but then the rest of the photons must be dumped. As a result, for most applications there is little benefit to the added quantum efficiency. Another drawback is that InSb infrared FPAs have been found to drift in their nonuniformity characteristics over time and from cool down to cool down, thus requiring periodic corrections in the field. As a result, the system becomes more complex by requiring thermoelectric coolers, and additional electronics in the camera. Thus, few manufacturers use InSb FPA detectors for measurement applications. The added complexity of an InSb system is generally warranted in applications where extreme thermal sensitivity is required, for example, long-range military imaging.

8.4 Ternary compounds

Ternary compounds made from III-V elements such as indium gallium arsenide (InGaAs) are already available. They operate in the near-IR region at 1 to 1.8 μm or higher, and no cryogenic cooling is required. Very good performance using thermoelectric cooling can be achieved below 1.8 μm . Linear arrays made from InGaAs elements is commercially available.

8.5 Alternate Indium antimonide detectors

Alternate Indium antimonide detectors based on InAsSb offer several advantages over InSb detectors. First, the addition of arsenic to the compound material, say (InAs_{0.80}Sb_{0.20}), increases the bandgap slightly and consequently reduces the maximum detectable wavelength to 5 μm compared to almost 6 μm for InSb. In this case, thermoelectric cooling is sufficient, with advantages such as compactness and reduced cost. When compared to ternary compounds such as MCT, manufacturing is more predictable; in the case of MCT, variation of the bandgap is much more sensitive to the relative composition of the elements in the material.

8.6 Platinum silicide detectors

Platinum silicide detectors operate in the short-wavelength region (1-5 μm), have good sensitivity (as low as 0.05°C), and excellent stability. It is manufacturable with semiconductor-production techniques, with fairly high detector yields resulting in reasonable costs. Platinum silicide has been desirable for measurement cameras and FPA's because it is a highly stable material that resists drift over time in its responsivity to temperature. One drawback is low quantum efficiency (<1%). However, modern signal-processing techniques coupled with hybrid construction and CMOS readouts have made PtSi a leading material for use in preventive maintenance and scientific IR imaging environments.

9. THIRD GENERATION IR SYSTEM REQUIREMENTS

Third generation IR system requirements rose into prominence due to NATO funding hastened after lessons learnt in GULF war [6]. NATO is funding development of components for passive IR detectors used for target surveillance, tracking, discrimination, and engagement during boost, ascent, midcourse, and terminal phases. Several technologies are being developed to address a wide range of target signatures, background environments, and sensor configurations.

9.1 Challenges faced

Challenges faced by IR detectors of third generation IR systems are long detection ranges, resolved and unresolved targets spanning very cold (un-illuminated decoys) to very hot (booster plumes), short observation periods, unique wavebands, precise tracking and thermal discrimination. The route for third-generation IR systems is currently being charted through Dual/Multispectral IR systems, polarized light detection and search for newer detector materials. Multispectral systems are envisaged to cover MWIR, LWIR, or both spectral windows.

9.2 Potential solutions

Detector candidates for the third generation There are four detector technologies that may meet specifications of third-generation IR systems: multispectral detectors, dualband monapixel, quantum-well IR photodetectors (QWIPs), uncooled microbolometer, antimonide based materials [7]. Uncooled detectors will probably be used for most low and mid-level applications in the near future.

9.2.1 Multispectral Detectors

Just as color images contain far more useful information than black and white ones, multispectral and hyperspectral detectors with multiple wavelength bands provide more information than conventional three-color images. Often, the experimental ones extend beyond the visual range into IR or/and ultraviolet (UV). Such detectors offer sensitivity to the degree that users can

distinguish individual species of trees from space or even identify moving, camouflaged tanks from great distances.

The most widespread approach to multispectral detectors involves splitting the incoming radiation with filters and then focusing the various spectral bands toward separate detectors. One example of this approach is the experimental Multispectral Thermal Imager Satellite (MTIS), which was launched at the end of 1999 with the goal of studying industrial facilities and related environmental impacts from space. Its core is a multispectral sensor consisting of linear detector arrays that have optical filters placed immediately above them in the focal plane of a telescope. The arrays, one for each required spectral band, line up along the track of motion of the satellite. As the satellite moves, a given image scans across each array in turn, allowing the system to build a two-dimensional (2-D) multispectral image.

The MTIS uses 15 bands ranging from a band of 450 to 520 nm to a band of 10.2 to 10.7 μm . It takes three separate multispectral arrays to cover the full 30-mm width of the device's focal plane. Each array uses three different detector materials to access the various wavelengths—silicon photodiode for visible wavelengths (450 to 860 nm), indium antimonide for near- and mid-IR (860 nm to 5.07 μm), and mercury cadmium telluride for the long wavelengths up to 10.7 μm .

The sensor chip assemblies contain photodetectors that are attached by indium electrodes to readout integrated circuits, which amplify and store the signals from each pixel. The resolution varies, depending on the wavelength. For the visible bands, 828 pixels are used, each 12.4 μm across, but for the IR bands, there are 207 pixels, each 49.6 μm across. These sensor characteristics allow a 5-m resolution for visible and a 20-m resolution for IR data spanning a width of 12 km.

For most space-based multispectral or hyperspectral sensors, the motion of the observing platform accounts for one of the scanning directions. In other multispectral applications, devices can provide information related to four dimensions—two spatial dimensions, wavelength, and time. For example, in real-time hyperspectral imaging, images are obtained at a video rate. Such imagers must therefore be able to scan in both spatial dimensions and produce vast amounts of data. For instance, the experimental multiband identification and discrimination imaging spectrometer (MIDIS) system under development by US Army Armament Research and Development Engineering Center (Picatinny Arsenal, NJ) and Surface Optics Corp. (San Diego, CA) generates more than 130 Mbyte/s.

9.2.2 Dual-band detectors

Whenever multispectral arrays of the type described here are used, multiple arrays, filters, and in many cases, beam splitters, add to device complexity, alignment problems, and cost. These issues are fueling research efforts to develop and fabricate single arrays with multiband capabilities integrated into each individual pixel. It may be impractical to integrate many bands into a single pixel, so hyperspectral imaging cannot use this approach, but research on two-band structures is very active, and three- and four-band structures may be possible within the decade. Dual-color detectors now in development are based on mercury cadmium telluride (HgCdTe) photodiodes and quantum-well IR photodetectors (QWIPs).

In either approach, the dual-band detector consists of a longer-wavelength detector behind a shorter-wavelength one so that the long-wavelength radiation passes through the first detector and is recorded by the second. For HgCdTe devices, the detector is an n-p-n triple layer heterojunction consisting of back-to-back p-n junctions (see Fig. 3). In the simultaneous-mode design, there is an additional electrical contact to the center layer that allows reading out each layer independently. In

the sequential mode design, the readout selects each layer and therefore each wavelength band through a change in the bias voltage.

The sequential approach has several advantages related to the fact that it only requires one readout connection per cell. This translates into smaller, more-reproducible unit cells and a nearly 100% fill factor. Nevertheless, since the construction of such devices does not allow independent selection of the optimum bias voltage for each layer, there can be substantial mid-wavelength crosstalk in the long-wavelength detector. The simultaneous mode avoids

A key technical issue in dual-layer detectors revolves around high dislocation densities. The cadmium zinc telluride (CdZnTe) substrates are matched to the lattice spacing of the long-wavelength IR HgCdTe layer. When the mid-wavelength IR HgCdTe layer, with a different ratio of Hg to Cd, is deposited on the substrate in dual-color devices, there is a small (0.04%) lattice mismatch, resulting in a higher density of dislocations. Despite the difficulties, several companies plan to market simultaneous-mode dual-band technology in larger array sizes in the near future, while development efforts continue to increase the number of bands covered to three or four.

9.2.3 Multispectral QWIPs

The main alternatives for multicolor devices are quantum-well IR photodiodes (QWIPs). Here, the dopants are concentrated into microscopic regions, creating quantum wells in which the band structure has shifted. Detection occurs when a photon knocks an electron or hole out of the quantum well into the neighboring band. Like HgCdTe detectors, dual-band detectors can be created by stacking long- and medium-wavelength QWIPs, each comprising repeated layers of indium gallium aluminum arsenide (InGaAlAs) surrounded by layers of indium gallium arsenide (InGaAs) and indium aluminum arsenide (InAlAs). With only one set of contacts, the observed wavelength depends on the voltage bias, with low voltage activating the long-wavelength detector and high voltage activating the mid-wavelength device to allow sequential readout. In such a detector developed at Northwestern University (Chicago, IL), for example, a 5-V bias has detection sensitivity peaking at 8 μm , and a 10-V bias has sensitivity peaking at 4 μm .

9.2.4 Microbolometer array

With advances in micromachining processes based on silicon processing techniques field of uncooled detectors has come off age. Even until the mid-1990s, sensitivity levels of the highest known uncooled sensitivity detector the bolometer was considered low. At room temperature, a radiation intensity of 1 mW/cm^2 leads, at equilibrium, to an increase in temperature of 1 K. One-tenth of that change in temperature produces easily detectable change in resistance. Since response time is proportional to the thickness of the absorber, with a micro machined bolometer of thickness of about 0.5 μm , response times drop to tens of milliseconds. This is fast enough for normal video camera operation at 30 frames per second.

Microbolometer array fabrication is done by etching material from around and under a 50- μm -square absorbing element, which in turn is supported by two electrical conductors, each only 0.1 μm thick and 5 μm wide. To isolate the element from underneath during fabrication, researchers use a sacrificial layer of polyimide, which ultimately dissolves away to free it. Thermal conduction through the tiny electrical conductors, which also serve as mechanical supports, is small enough that thermal sensitivities are excellent. During the fabrication process, a thin aluminum layer is inserted underneath the absorbing element or microbridge to reflect the IR back up into it. The element itself combines a very thin layer of titanium nitride to absorb the IR radiation with a 0.1- μm layer of amorphous silicon that acts as the thermometer. Given next is a magnified view of microbolometer array.

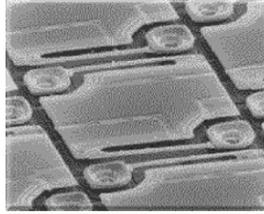


Fig. 10.2. Magnified view of microbolometer array

The individual microbolometers are formed as part of a square array of typically 256 x 256 pixels. A single silicon wafer can hold 12 such arrays. Since ordinary silicon and integrated circuit materials and processing techniques are used, yields are high, and the costs of production are far lower than for quantum arrays.

Within each bolometer, the absorbant material separates the conductors from each other. This is done by putting the conductor on opposite sides of the absorber, forming a gap design, or by locating one conductor on top and the other underneath the absorber to form a sandwich or a combined sandwich gap. By tailoring the thickness of the absorbing material, typically lightly doped silicon, the device manufacturers ensure that it combines high absorption in the mid-IR band around 10 μm with fast response time and good resistivity characteristics.

Other materials used are barium strontium titanium oxide, titanium, and vanadium oxide in the fabrication process. The resulting bolometers are highly sensitive, capable of detecting temperature differences of 0.07 K with output response of about 10 mV/K. Uncooled microbolometer arrays are now widely available in commercial imaging cameras, although they remain fairly expensive. As prices for these arrays drop, the cost of IR cameras will drop radically as well, enabling a rapid expansion of applications.

10. FUTURE TRENDS

Third generation of IR systems are essentially the future trends in this industry that has enjoyed the patronage of US Department of Defence (DoD). However, it can be said that in future, the performance of detector formats with cooled or uncooled FPA technologies will be further enhanced by development of new detection methodologies and signal processing techniques [4]. Moreover, the concept of military and commercial dual-use technology in IR detector formats will lead to lower cost, small size, reduced weight and increased user friendly application-oriented development. Some advanced development directions on IR imaging systems and detectors and systems such as on-FPA signal processing, optical link, smart FPA concept, FIRST, etc are discussed briefly.

10.1 On-chip A/D conversion

On-chip A/D conversion is an advanced circuit technology that is applied to IR FPA chips. Due to conversion to the digital output on FPA itself, signal of IR FPA chips avoids noise coupling during the transfer out of cooling systems and Dewars. Thus, the system design can be simplified and the cables and IC chip counts can be reduced. However, the additional power and area consumption on the FPA may not be acceptable in some applications. Thus, the on-chip A/D conversion is usually used in high-performance scanning array applications. Raster array applications may not prefer it due to requirement of area of FPA for IR detection at all times.

10.2 Optical Link technique

Optical Link technique can reduce loading of cable capacitance in a readout chip. The loading of parasitic heat from thermal detectors and the noise coupling degrade the system performance. This can be improved by optical link techniques. An analog optical modulator on the FPA is designed to transfer output signals. In this configuration, all the noise, loading, and coupling effects of the conventional cables can be avoided. The optical signals can also be digitized before sending to the optical link. This can further improve performance at the expense of additional power dissipation.

10.3 Smart Focal Plane Array

The on-FPA signal processing technologies are used to support front-end signal processing that can significantly reduce the downstream system loading and improve readout performance. Some smart functions such as bad pixel substitution], pixel averaging, and neural FPA concept are being researched. Neural network concept is being studied to achieve the on-chip image extraction and motion detection. A new sensing structure has been proposed to implement CMOS silicon retina systems using multi-emitter bipolar junction transistors (BJT's). The new BJT-based silicon retina can perform some smart functions like edge detection, pattern recognition, and motion detection in simple and compact detector arrays. Other image processing functions including contrast and quality enhancement, image compensation, and nonlinearity fix for implementation on-chip to achieve smart FPA's are also on fore.

10.4 Advanced QWIP's

Research is advancing rapidly in these devices, concentrating on gallium arsenide-based systems, such as GaAs/AlGaAs, with the latter compound being used to create the quantum wells. QWIPs use the manufacturing techniques of the mature GaAs chip technology and thus have both high uniformity and low cost compared with HgCdTe. In the wavelength range from 8 to 10 μm , QWIPs have been approaching HgCdTe in performance, although at longer wavelengths the ternary compounds still have an edge. Like the extrinsic detectors, QWIP's generally have to be cooled below liquid-nitrogen temperature for background-limited performance.

10.5 FIRST

European Space agency is making plans for FIRST, the far infrared and submillimeter space telescope, which will open up the one spectral band not yet surveyed—from 60 to 670 μm . The design will use arrays of germanium gallium photoconductors for 100 to 200 μm and arrays of bolometers cooled to 0.1 K for the rest of the band.

11. CONCLUSION

The IR industry is in transition. After years of existence as an esoteric technology reserved for military, academia and narrow niche markets, IR technology is on the brink of emerging as a dramatic new mainstream tool for countless applications, including security, firefighting, surveillance, and industrial imaging. Two-waveband FPAs improve the detection of targets with various surface temperatures and enable real-time thermal discrimination. Operation at longer wavelengths enables detection of cold targets at long ranges. Large-format (256 x 256 pixels and larger) FPAs provide large search areas concurrently accurate tracking. Improved operability and yield reduce production costs and schedules.

The advent and continuing maturation of newer technologies like MEMS-based uncooled detector technologies, wafer-scale manufacturing, etc shall help completely eliminate cooling

requirements or reduce need for temperature stabilisation. Thus, promising true mass-production potential. As with any highly elastic market, as the prices come down volume markets will emerge. From the night-vision option in automobiles to thermal imager used by surgeons, everyday life will be impacted. Nonvisible imagers will be as ubiquitous as camcorders. And as the technology becomes widely available and understood, bright minds and entrepreneurs will discover countless new applications for this exciting and enabling technology.

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