Recent advances in thermal imaging and its application in military

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ABSTRACT

Infrared cameras are versatile technology studied and utilized in enormous distinct applications ranging from human life-supporting fields such as industrial, building science, and medical to research and development area. Especially the exploitation of thermal imaging of infrared detectors is a potential candidate in military equipment and weapon for observing the target accurately in long-distance with many obstacles. The modification in thermal imaging sensors structure with uncooled and cooled detectors provides new concepts of incredibly sensitive devices with thermal. Here, the technical developments in Gen-generation devices for thermal imaging are discussed and studied outstandingly.

Keywords: Thermal imaging; Infrared camera; Gen-generation; HgCdTe detector.

1. INTRODUCTION

The thermal cameras are equipped with an infrared detector in a focal plane array, which is known as detecting elements. It is a superior visible imaging technique due to the overcome of external conditions such as smoke, aerosols, dust, and mists [1, 2]. The exploitation of infrared focal plane arrays (IRFPAs) provides vast capability in both civil and military applications, for instance, remote sensing, firefighting, security, pollution monitoring, leak-testing, night vision, missile guidance, surveillance, and reconnaissance.

Recent studies revealed that the modification in the infrared detector structure contributed to the enhancement of the imager's performance. The fabrication process of HgCdTe materials uses molecular beam epitaxy (MBE) on different substrates (i.e. CdZnTe, Si, and GaSb) for IR detection was reported by Wang. X [3]. The fundamental physical properties of two material systems, HgCdTe and T2SLs are compared together with their influence on detector performance: dark current density, RA product, quantum efficiency, and noise equivalent different temperatures [4]. Ciura. L et al. [5] use mid-wavelength infrared (MWIR) InAsSb-based devices with different absorber doping and the heterojunction HgCdTe detector to investigate the frequency noise with 1/f – like spectrum shape. In this review, fundamental technology regarding thermal imaging was introduced and compared obviously through the generation of an IR detector array and associating equipment in the thermal imaging system.

2. THE FUNDAMENTAL TECHNOLOGY OF THERMAL IMAGING

2.1. The components of an infrared thermal imager

A thermal imaging system combines four fundamental components: the optical system, the infrared optical system, the signal processing units, and the display system. These devices are used to detect the thermal infrared radiation emitted from the object without using artificial illumination [6]. As shown in figure 1, the thermal imaging system views the target or the scene through the detecting optics (lens) system, which focuses the received infrared rays into the photosensitive elements of the infrared detector array. Afterwards, the infrared radiation is converted to an electrical signal and amplificated through the signal processing unit and eventually is visualized as the temperature pattern on the monitor or LED screen.

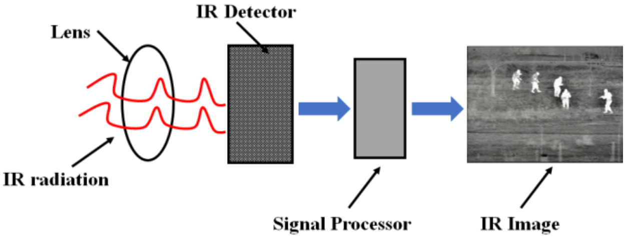

***Figure 1.** Basis components of a thermal imaging camera.*

In terms of the focal plane array (FPA) refers to a one-dimensional as well as two-dimensional assemblage of individual thermal detector picture elements or pixels located at the focal plane of an imaging system, whereas each pixel contains a sensitive layer connected to the substrate [7]. The staring arrays are scanned electronically using a circuit integrated with the arrays. The architecture of a read-out integrated circuit includes the function of pixel deselecting, antiblooming on each pixel, subframe image, and output preamplifiers, which belong to the second-generation system, to be discussed in a further section.

The infrared detector array is classified into cooled and uncooled, depending on the materials comprising the array and the intended use of the camera [8]. All infrared detectors are cooled to a cryogenic temperature close to 77 K. The photon captured is directly transferred into electrons, leading to the accumulation of charge. Therefore, the current flow and the change in conductivity are proportional to the infrared intensity of the object in the scene. Meanwhile, the common uncooled cameras are based on the micro-bolometer. These detectors operate under room temperature and work by measuring modulation in resistance, voltage, and current when heating the incident infrared radiation. The bolometer is a typical resistive element constructed from a material, indicating thermal capacity and a positive temperature coefficient. Due to good thermal insulation, the incident IR energy is absorbed completely according to temperature increase. Differing from the cooled detector, the resistance-changing mechanism attributed to the heating produced from radiant power and reacting with the sensing area instead of photon-electron pair interaction [9].

2.2. The first and second generations of infrared thermal detectors

The start-of-art IR imager has been combined with semiconductor material based on microelectronic technology aiming to develop novel devices for integrated circuits.

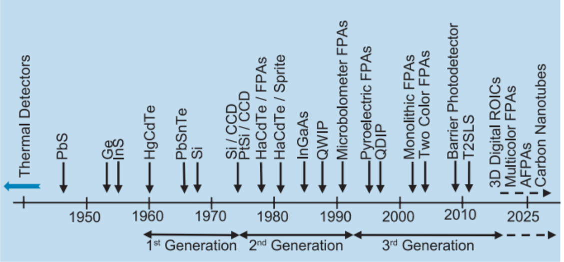

***Figure 2.** The timeline of generation of infrared thermal detectors [10].*

Two families of the multielement detector are utilized for military and civilization applications, including a scanning system and starting system, corresponding to the first and second generation. The first IR photoconductor was developed in the 20th century with a response of about 3 micrometers. As shown in figure 2, the first-generation detector configuration comprises a single element or linear array of photoconductors. The thermal image is generated based on the scanning of the scene across the trip and mapping point by point using a mechanical scanner. Some external factors, namely dark noise and amplifier noise, are the priority barrier to IR detectors. To deal with this issue, there are many efforts to improve sensing materials, and microelectronics have been experimented with. The second-generation IR detector technology used photodiodes with integrated detection and readout circuits instead of photoconductors. The starting FPA is a two-dimensional array containing individual detector pixels, which are scanned electronically.

2.3. The third generation of infrared thermal detectors

Multispectral infrared focal plane arrays provide favor characteristics, for instance, high sensitivity at a specific range of wavelengths, high resolution cooled imaging with multi-color bands, low-noise and viable simultaneous acquisition of images, and narrow-band spectral information without utilizing optical instruments, and mechanical scanning structure. Being developed on the traditional hybrid structure detector with a 2D array of indium-bump interconnects to the silicon readout, third-generation IR imagers have studied the heterostructure devices, including hybrid structures from ternary alloys and quantum wells. The use of multi-color starting makes the signal-to-noise ratio increase and allows long wavelength IR (LWIR) focal plane arrays to improve the sensitivity by over 10 times.

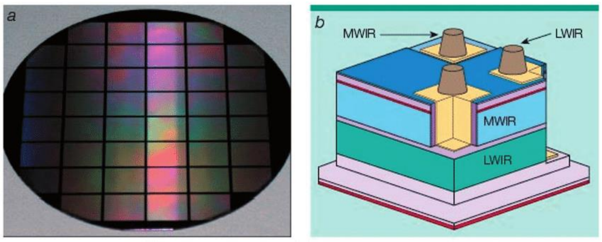

Figure 3. *The two-color MWIR/LWIR QWIP detector.*

A potential candidate for a third-generation infrared detector for middle wavelength IR (MWIR) and long wavelength (LWIR) spectral ranges are based on multiband quantum well detectors. A QWIP only absorbs the narrow spectral band in the IR radiation and is transparent outside of that adsorption band, hence QWIP detector co-registered simultaneously two-color IR FPAs and provides zero spectra cross-talk. This device detects simultaneously two separate wavelengths in cases of vertical stacking of the different QWIP layers during epitaxial growth, for instance, growing the long wavelength-sensitive stack (red QWIP) on the shorter-wavelength-sensitive stack (blue QWIP), as depicted in figure 3.

2.4. Thermal sensor in military application

Thermal sensors are gaining traction in a broad range of markets, especially in military applications. With a cooled sensor, the heat is cooled between 40 K and below room temperature (most cameras of this type now operate in the 60 - 100 K range). The feature of this type is that it gives a higher-quality image than many uncooled types. The downside of this camera is that it is more expensive and consumes more energy (for the cooling system), and takes time to cool down. However, due to its high sensitivity, this type of camera allows adding a lens with a large focal length (large F-number), which reduces the size and cost of the additional lens, thereby allowing observation with high sensitivity long-distance. Current projects are commonly using an uncooled sensor, the sensor is stable and works at ambient temperature. This allows cameras of this type to be smaller and cheaper but with lower resolution and image quality.

3. CONCLUSIONS

Thermal imaging is an emerging tool for numerous military and civil applications. The key technology in the thermal imagers system belongs to the IR detector arrays which are used as a receiving part of the infrared radiation emitted from objects in the scene. Many studies experimented over a long-term period to develop the IR detector structure to deal with the limitations of the first generation. In this review, we provide recent pieces of research on innovation of the configuration of IR sensors, for instance, replacing the one-dimensional linear array with the two-dimensional structure coupling with indium bump bonding the readout electronics. With the improvement in fabricating technology, the novel generation of IR detectors allows to co-registered simultaneously multi-color bands to be applied in the common thermal imaging system.

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TÓM TẮT

Những bước tiến bộ của công nghệ ảnh nhiệt ứng dụng trong quân sự

Camera hồng ngoại là công nghệ đã được nghiên cứu và ứng dụng trong nhiều lĩnh vực, từ công nghiệp, xây dựng, y tế đến các lĩnh vực nghiên cứu và phát triển. Đặc biệt, công nghệ ảnh nhiệt là một ứng viên tiềm năng thường được sử dụng trong các thiết bị quân sự. Việc sửa đổi các loại cấu trúc vật liệu của cảm biến ảnh nhiệt cùng với sự phát triển các loại cảm biến không được làm lạnh và có làm lạnh cho ra đời các khái niệm mới về các thiết bị cực kỳ nhạy với nhiệt. Trong bài báo này, tác giả tập trung thảo luận và nghiên cứu những bước tiến bộ trong nghiên cứu phát triển các loại cảm biến ảnh nhiệt.

Keywords: Ảnh nhiệt; Camera hồng ngoại; Thế hệ mới; Cảm biến hệ vật liệu HgCdTe.