Infrared Detector Technology to Support Public Safety

SASAKI Tokuhito, KURASHINA Seiji

Abstract

Compared to conventional cooling type infrared detectors, uncooled infrared detectors are smaller and less expensive and it is for that reason aimed to expand their fields of applications. The targeted fields include those of security and thermography. This paper introduces the technologies used for NEC's uncooled infrared detectors together with examples of their applications. In addition, it introduces the technologies used for uncooled terahertz detectors that have been newly developed based on technologies used hitherto for uncooled infrared detectors and to suggest future fields of application for the terahertz detectors.

Keywords

uncooled, infrared radiation, terahertz, bolometer, diaphragm, MEMS, vacuum package

1. Introduction

In about the year of 1800, William Herschel, a British scientist discovered invisible infrared radiation. Infrared radiation remains unaffected by visible radiation such as spotlights and headlights. It is used to detect body temperature and is also used to detect physical bodies that are hidden by fog and smoke, etc. In order to detect infrared radiation, cooled infrared detectors have been used in the past. These detectors use particular kinds of semiconductors as the detector materials, and they require a cooling unit to be cooled to a temperature below -196 deg C in order to exert their optimum performance. As a result, cooled infrared detectors incorporating cooling units are bulky and their cost includes the maintenance of the cooling unit. These factors have been a disincentive for market penetration of infrared detectors.

On the other hand, with recent advances in the micro-fabrication technologies for semiconductors, it has been possible to form structured devices called MEMS (Micro Electro Mechanical Systems) on the substrates. MEMS are thermally isolated from the substrate and the technology has begun to be used for thermal detectors. Uncooled infrared detectors evolved from the use of this technology. Since uncooled infrared detectors can be formed on a signal readout circuit, and they do not require cooling units, they have become widely used as inexpensive infrared detectors. This paper explains the elementary technologies used for uncooled infrared detectors and introduces examples of their applications. In addition, these detector technologies are used to develop detectors for terahertz waves. We will also consider these new technologies.

2. Key Technologies Used for Uncooled Infrared Detectors

(1) Device Structure and Bolometer Materials

The size of one unit pixel of NEC's uncooled infrared detector is 23.5 μm. This size is about a third of that of the thickness of a human hair. **Fig. 1** shows the structure of an uncooled infrared detector.

The structure is realized by utilizing MEMS technologies featuring the micro-fabrication method known as "Semiconductor Photolithography" and the structure is directly formed onto a silicon substrate. In the case of uncooled infrared detectors, it is necessary to isolate the circuit from heat and the readout circuit is supported only by two long and slender beams. This hollow structure (diaphragm) consists of

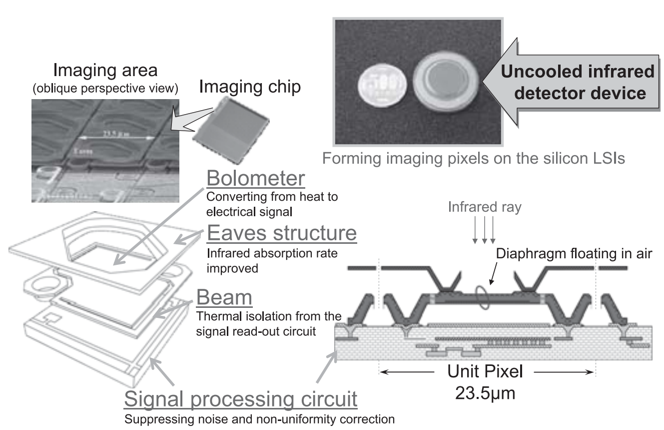


Fig. 1 Structure of an uncooled infrared detector.

insulating films (i.e. silicon nitride films), and the structure is formed on a base called a sacrificial layer, the thickness of which is as thin as only 1.5 µm. This layer is removed by etching at the final production process. In the sacrificial structure, a film of a metal oxide material called a bolometer is formed and processed. The resistance value of the bolometer is sensitively changed by heat.

Incident infrared radiations (wavelength: 10 µm band) are absorbed by the silicon nitride films, the temperature of the diaphragm rises and the resistance value of the bolometer is changed by an increase in temperature. By applying current to the bolometer, it is possible to read out the change in the resistance value (i.e. the signal component of infrared radiation) as an electrical signal and to transmit the value from the chip.

At NEC we have employed a unique infrared absorption structure called "Hisashi (i.e. eaves in English)" [1) that is designed to efficiently absorb the infrared radiations that are incident upon the pixels.

For the material used for the bolometer, metal oxide having a high temperature coefficient of resistance is employed (i.e. material showing a wide range of changes in the resistor value according to changes in the temperature).

However, generally in the manufacturing process of semiconductors, materials having high temperature coefficients of resistance are not used; therefore, at NEC we started to develop the materials before we developed the technologies for film formation and processed them on a silicon substrate.

(2) Vacuum Packaging

If there are gas molecules such as air around the pixel diaphragm, the heat absorbed in the diaphragm is lost by the heat conduction of the gas molecules, which results in reduced sensitivity of the detector. In order to suppress such loss, it is necessary to encapsulate the pixel diaphragm with the chip substrate in a vacuum by using a vacuum packaging technique. Vacuum packaged pixels require a window to capture incident infrared radiation. Since common glass does not transmit infrared radiation, a germanium (Ge) with an antireflection film is used as the infrared window for the imaging area of the vacuum packaging (refer to the picture in **Fig. 2**). Recently, tubeless vacuum packaging is becoming the mainstream. This type of vacuum packaging does not require an exhaust tube inside the package to enable evacuation.

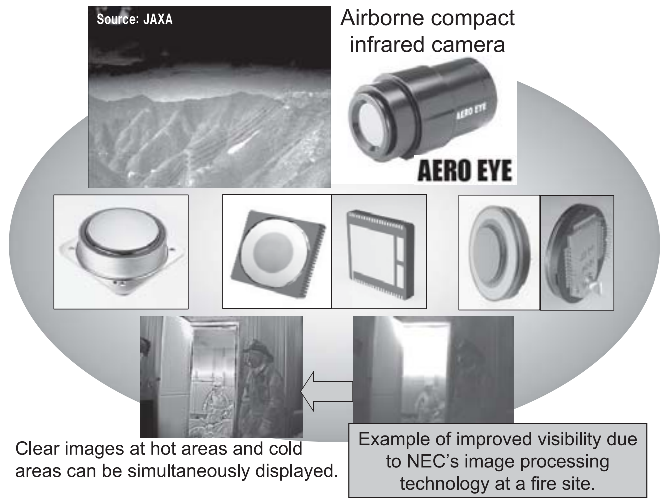


Fig. 2 Uncooled infrared detectors (packages) and examples of their applications.

(3) Signal Processing Circuit

In the case of the infrared radiation detector, noise generated by the signal processing circuit and component variability can be a significant issue, since the signal created by the infrared radiation is extremely weak. In order to solve this issue, the signal processing circuit is designed to have features to suppress noise and to adjust the non-uniformity of the pixels.

3. Application Fields of Uncooled Infrared Detectors

Uncooled infrared detectors have been realized by combining the fundamental technologies explained in Chapter 2, which has enabled the development of the compact and inexpensive infrared cameras used for thermography and security purpose, etc.

Other applications include the airborne compact infrared cameras (pixel configuration: 640 × 480) shown above in Fig. 2. These cameras help airplane pilots to promptly recognize hazardous obstacles such as ridge lines and electric power feeder lines. This means that the cameras can be used as important tools to support safe aircraft operations.

Just as it is difficult for visible light detectors to simultaneously display both strong and weak lights, it is also difficult for infrared detectors to simultaneously display both hot and cold areas. However, in order to resolve this issue, we at NEC have developed a technology to simultaneously display hot and cold areas by utilizing image processing techniques. For example, in the case of a fire, it has become possible to secure a high level of visibility by simultaneously displaying hot areas (the flames, etc.) and other cold areas (refer to the picture below in Fig. 2).

4. Reductions in Price and Planned Expansion of the Uncooled Infrared Device Market

As described above, the application fields of uncooled infrared detectors are expanding in step with their spread. **Fig. 3** shows the evolution of uncooled infrared detectors developed by NEC. At NEC we have successfully reduced pixel size and improved the pixel configuration from the QVGA size (pixel configuration: 320 × 240) to the VGA size (pixel configuration: 640 × 480). However, it is necessary to respond to the demand for further reductions in both the price and the size of detectors in order to expand the market even more. One of the suggested solutions aimed at responding to the demand is a further reduction in the pixel size. A reduction of pixel size makes it possible to reduce the size of the chip while maintaining the same pixel configuration, which results in a reduction in the size of the entire detector vacuum package. In addition, in the case that the field of view remains the same, a smaller pixel size enables the use of a smaller diameter lens. This reduces the cost of the infrared lens, which uses expensive Germanium materials. It is expected that such cost reductions will result in further reductions both in price and size.

However, the reduction in the pixel size will also result in a reduction in the amount of incident radiation in proportion to

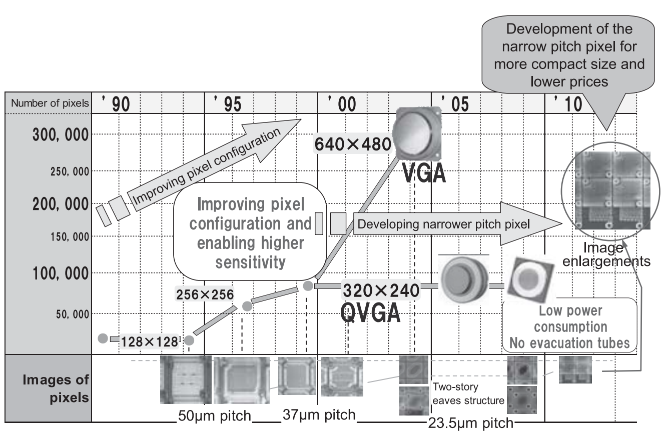


Fig. 3 Evolution of the uncooled infrared detector developed by NEC.

the pixel area. In addition, the pixel size itself is approaching the diffraction limit of the 10 µm wavelength band (approximately 12 µm) handled by infrared detectors and it is considered that the amount of light will be reduced more than the ratio of the pixel area. Therefore, it will be necessary to develop new pixel technologies to compensate for this reduction. In order to solve these issues, we at NEC are developing narrow pitch pixel technologies by utilizing new structures.

5. Terahertz (THz) Detector

(1) What is a Terahertz Wave?

Terahertz waves are defined as the electromagnetic waves in the range of frequencies approximately between 0.1 and 10 THz. The wavelengths of Terahertz waves are between 3 mm and 30 µm, and the range of wavelengths is between those of radio waves and light waves. However, terahertz wave R&D has been at quite a preliminary stage, and the terahertz waveband is called the “unexplored frequency domain”. The reasons for the delay in R&D include the difficulty of obtaining easy-to-use imaging detectors and high-intensity light sources and the significant influence on terahertz waves of the atmospheric absorption of the earth. On the other hand, the utility value of terahertz waves is highly regarded, and it is anticipated that they will be utilized over a wide range of applications. The expected applications include medical fields, biotechnology, security purposes and the short-distance transference of mass data.

The terahertz wave in the frequency band of approximately 0.5 THz or lower (wavelength: 600 µm or higher) has a high transmittance value on clothes. The characteristics are proven to be effective for the detection of deadly weapons hidden in clothes, etc. Products utilizing such characteristics have therefore been commercialized [2]. On the other hand, in the case of the terahertz waves in the frequency band of 0.5 THz or higher, high-molecular-weight biological polymers have absorption bands that can be attributed to the slow twisting movement throughout whole molecules and the mode of subsonic vibration caused by the weak bonding of hydrogen. These characteristics are considered to support applications in the medical fields, drug discovery research and life sciences. For example, at present, it is impossible to judge if an antigen-antibody reaction occurs without the process of adding labeled molecules or enzymes. However, it is considered that the terahertz wave has the potential to enable examination without using labeled molecules or enzymes. In addition, since the terahertz wave has a very long wavelength, its ratios of scattering and extinction by dust are lower than those of visible light and infrared radiation. The terahertz wave is therefore expected to contribute to confirming if any of the victims remain alive at disaster sites and search areas.

In order to realize the abovementioned applications, it is essential to develop suitable technologies to support real-time terahertz wave imaging.

(2) Development of the Terahertz Detector

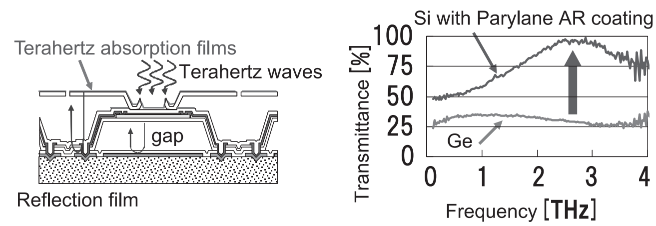
At NEC we have developed 1) an absorption structure for the terahertz wave and 2) the materials for windows that feature high transmissivity (refer to **Fig. 4**).

1) Development of an Absorption Structure for the Terahertz Wave

The illustration at the left side of Fig. 4 shows a cross-section of the pixel component structure of a terahertz detector. As is evident from a comparison with Fig. 1, the detector has a structure in which terahertz absorption films (metal thin films) are added to the pixels of an infrared detector. An absorption factor of approximately 20% is obtained at the frequency of approximately 3 THz (wavelength: 100 μm) by appropriately setting the sheet resistance value for the terahertz absorption films. The obtained absorption factor is significantly higher than that obtained by using the conventional uncooled infrared detector (: approximately 3%[4]).

2) Development of High Transmissivity Materials for Windows

With regard to the transmissivity of terahertz waves, the transmittance of germanium (Ge) used for the package window of the uncooled infrared detector described in Chapter 2 may be as small as approximately 30% (refer to Fig. 4). For the terahertz detector, window materials having higher transmissivities are essential. Past research has indicated that silicon (Si) having a high resistivity is the most suitable material for windows and lenses. However, since the refraction index of silicon is as high as 3.42, and its reflection ratio is as high as approximately 30%, it is necessary to form antireflection films to increase the



1: Development of terahertz absorption structure

2: Development of high transmissivity materials for terahertz windows

Fig. 4 Concerns regarding terahertz detector development.

transmissivity for terahertz waves. At NEC we have developed a suitable antireflection film for the terahertz wave and we have successfully achieved transmissivity of 90% or higher at the frequency of 3 THz (wavelength: 100 μm) (refer to the illustration at the right of Fig. 4).

(3) Imaging the Terahertz Wave

By developing the aforementioned 1) absorption structure for terahertz wave and 2) high transmissivity materials suitable for windows, NEC has successfully developed a high sensitivity imaging technology for the terahertz wave. **Fig. 5** shows examples of imaging.

The left side of Fig. 5 shows an example captured by the terahertz detector. What is captured is the quantum-cascade laser (oscillating frequency: 3 THz, wavelength: 100 μm) developed by National Institute of Information and Communications Technology. For comparison, Fig. 5 also shows the laser beam profile captured by a conventional uncooled infrared detector (note: the vertical scale is enlarged × 5 times). Fig. 5 clearly indicates that the terahertz detector developed by NEC has much higher sensitivity for terahertz waves than the conventional uncooled infrared detectors.

The picture at the right side of Fig. 5 is an example showing the detection results of a small molecule-protein response in the absence of labeled molecules or enzymes. The conventional method requires the process to add labeled molecules or enzymes in order to detect a response. However, this example clearly shows that NEC's terahertz

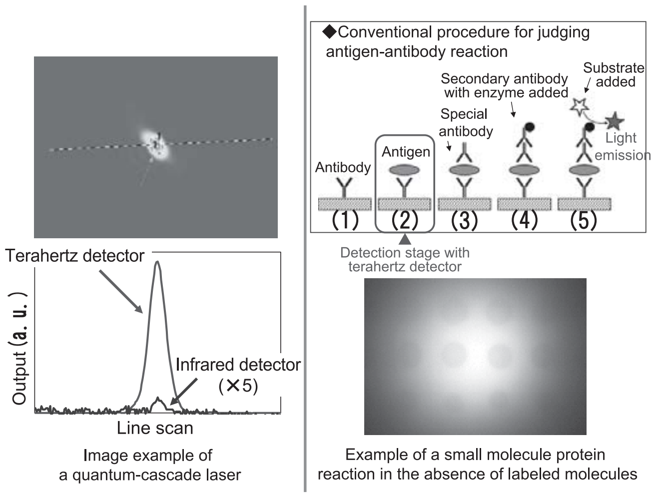


Fig. 5 Example of imaging using a terahertz detector .

detector can detect the molecule-protein response without adding any labeled molecules or enzymes (The sample was provided by associate professor Ogawa of the University of KYOTO).

With regard to the terahertz detector, there is room for further improvement in detector sensitivity by adopting optically resonant structure optimization. At NEC we continue to make efforts to improve the sensitivity of the terahertz detector and to aim at its utilization over a wide range of application fields in the future.

6. Conclusion

As reported above, uncooled infrared detectors are gaining recognition as important data input devices for supporting public safety and it is expected that their applications fields will increase more and more in the future. With regard to the terahertz detector, as mentioned at the beginning of Chapter 5, it is expected that the applications fields will expand by further improving sensitivity and by establishing detector technology as one of the key terahertz measurement technologies.

In terms of the narrow pitch pixel technologies mentioned in this paper, the development has been carried out under the contract research (Title: "Design examination and trial production of components regarding the formation of a large format for uncooled infrared detectors") entrusted by the Japan Aerospace Exploration Agency (JAXA). In addition, in terms of the terahertz detector, the development has been carried out under the contract research (title: "Research and development of terahertz wave technologies to realize safety and security by ICT") entrusted by the National Institute of Information and Communications Technology (NICT). In conclusion, we would like to express our deep thanks to these organizations for giving us such valued opportunities to perform the related research and development.

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Authors' Profiles

SASAKI Tokuhito
Senior Manager
Guidance and Electro-Optics Division
Aerospace and Defense Operations Unit

KURASHINA Seiji
Expert Engineer
Guidance and Electro-Optics Division
Aerospace and Defense Operations Unit