8 Sponsored Research

8-1 Development of Remote Imaging Technologies at Terahertz Frequency

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Terahertz (THz) radiation, 1-10 THz, has shown promise for security imaging application. For this application, real-time imaging technology will be highly desirable, which requires two-dimensional array sensor. The author has succeeded in detecting 3.1 THz radiation from Quantum Cascade Laser (QCL) for the first time in Japan, using vanadium oxide (VOx) microbolometer focal plane array (FPA) of 320×240 with 23.5 μm pitch. Noise Equivalent Power of FPA at 3.1 THz is measured to be 200-400 pW. The success in THz detection and further improvement in sensitivity will provide VOx microbolometer FPA with new applications.

Keywords
Microbolometer, Focal plane array, Terahertz, Real-time imaging

1 Introduction

Terahertz (THz) waves cover a frequency range from 0.1 THz to 10 THz (i.e., the wavelength range from 30 μm to 3 mm). Due to the relatively long wavelengths involved, scattering extinction by dust is smaller for terahertz waves than for visible or infrared light. Accordingly, terahertz waves are considered promising for applications involving so-called "situational awareness" (including, for example, the search for survivors) at disaster sites. As situational awareness requires speed, real-time imaging technology is indispensable. To develop practical applications of this technology — in other words, to design the terahertz sources and cameras that will be useful in situ, we will need to understand the absorption characteristics of atmosphere and the spectroscopic characteristics of living bodies.

In this article we first describe the concept behind a real-time imaging system in the terahertz range, which is one of the sponsored research themes relating to research and development of advanced communications and broadcasting technologies performed at the National Institute of Information and Communications Technology (NICT). We then report on measurement results related to the present performance of the focal plane array (FPA), the key component of the imaging system. Finally, we describe the elemental technologies for improving the responsivity of the imaging system.

2 Terahertz real-time imaging system

2.1 Overview of system

Figure 1 shows an overview of the real-time terahertz imaging system we are working to develop. This imaging system consists of a passive imaging camera, an active imaging camera, and a terahertz source. The passive imaging camera takes quasi-real-time images of an area approximately 1 m square from a

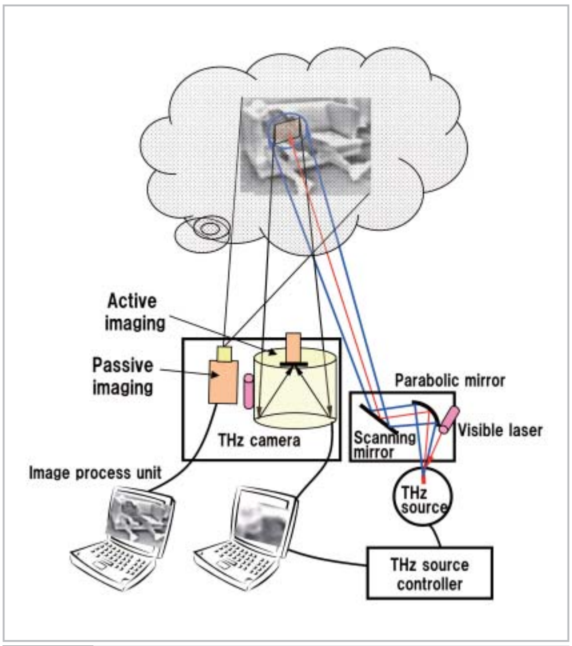

Fig. 1 *Overview of terahertz real-time imaging system*

distance of approximately 5 m. The system then irradiates terahertz waves to an area of approximately 10 cm square targeted within the 1-m square area, detects the scattered wave by an active imaging camera, and analyzes the results in detail. Our present model of operation focuses on the search for survivors at disaster sites, a difficult task using visible or infrared light.

2.2 Responsivity of uncooled infrared focal plane array to terahertz waves

We assume that we will be able to use the sensors employed in the passive and active imaging cameras based on the uncooled infrared focal plane array, combined with techniques for providing higher responsivity to terahertz waves. We will discuss this issue later. First, we report on the results of measurements we conducted to verify whether a presently available uncooled infrared focal plane array for the 10-μm wavelength range has responsivity to terahertz waves.

Figure 2 shows the experimental configuration. We used a quantum cascade laser (QCL)[1] as the terahertz source and the TVS-200EX as the infrared camera, which is

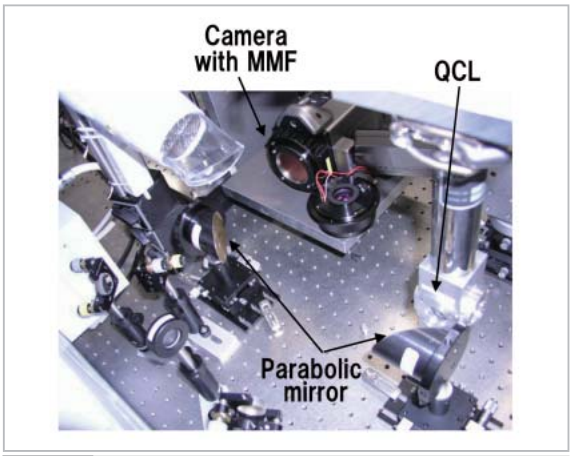

Fig.2 *Configuration of terahertz wave detection experiment*

equipped with an HX0830 uncooled infrared focal plane array consisting of 320 × 240 pixels with a pixel pitch of 23.5 μm[2]-[4]. As the lens of the camera is designed for the 10-μm wavelength range, we removed the lens and collimated the terahertz waves from the QCL on the array sensor using off-axis parabolic mirrors. We placed a metal mesh filter (MMF) in front of the array sensor to pass only terahertz waves at wavelengths from 70 μm to 105 μm and to block waves in the 10-μm wavelength range. As shown in Table 1, the oscillation frequency of the QCL is 3.1 THz (wavelength of 97 μm), the duty cycle is 0.03 %, the peak power is 31 mW, and the time-averaged power measured by the power meter is 8.7 μW.

Figure 3 shows a real-time image (displayed with 320 × 240 pixels) of the 3.1-THz line emission from the QCL. Figure 4 shows the intensity distribution along the vertical line indicated by the number "2" in Fig. 3. Here, the beam image is elongated primarily because the two off-axis parabolic mirrors are

Table 1 *Specifications of QCL*

Laser frequency	3.1 THz (Wavelength 97 μ m)
Operation temperature	15 K
Pulse width	300 nsec
Repetition period	1.07 msec
Peak power	31 mW
Power meter output	8.7 μ W

not perfectly aligned but instead have different focal lengths in perpendicular directions. Nevertheless, the size of the image is approximately the same as the diameter of the power meter detector (2 mm) and thus we can use the data obtained in this experiment to calculate the noise equivalent power (NEP) of the uncooled infrared focal plane array described above. The image extends over an area of 1,139 pixels enclosed by the contour of the half value. The transmittance of the MMF is 74 %, and the transmittance of the Ge window of the vacuum package is 26 %. The signal-to-noise ratio is 6 to 7. These values indicate that the NEP of this sample is approximately 200 pW to 250 pW. For another sample, the NEP was approximately 400 pW. These values are equivalent to the NEP of an uncooled infrared focal plane array with 320 × 240 pixels and 37- μm pixel pitch[5] and the NEP value of 300 pW obtained by a group at MIT[6]. The NEP values from 200 pW to 400 pW correspond to absorbance of 2 % to 4 % (See Fig. 6, discussed later). Here, the NEP of the 320 × 240-pixel uncooled infrared focal plane array is approximately 10 pW in the 10- μm wavelength range, which corresponds to 80 % of the absorbance.

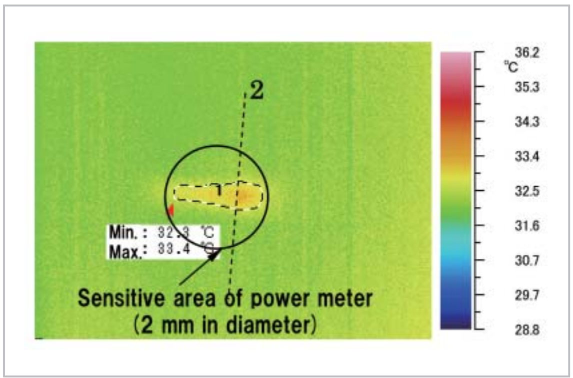

Fig.3 *Real-time image of terahertz waves from QCL*

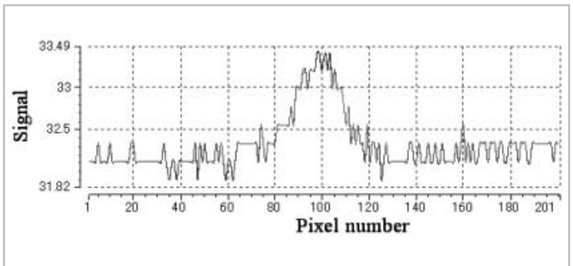

Fig.4 *Intensity distribution of terahertz waves*

2.3 Measures for improving responsivity

Several measures may be proposed as effective means of improving the responsivity of the present uncooled infrared camera to terahertz waves: (1) increasing responsivity by modifying the structure of the array sensor, (2) increasing transmittance of the package window of the array sensor, and (3) improving the signal-to-noise ratio by integrating the image. Here, we report on our ideas and achievements to date with respect to approaches (1) and (2).

Figure 5 illustrates a concept aimed at improving the responsivity of the uncooled infrared focal plane array to terahertz waves

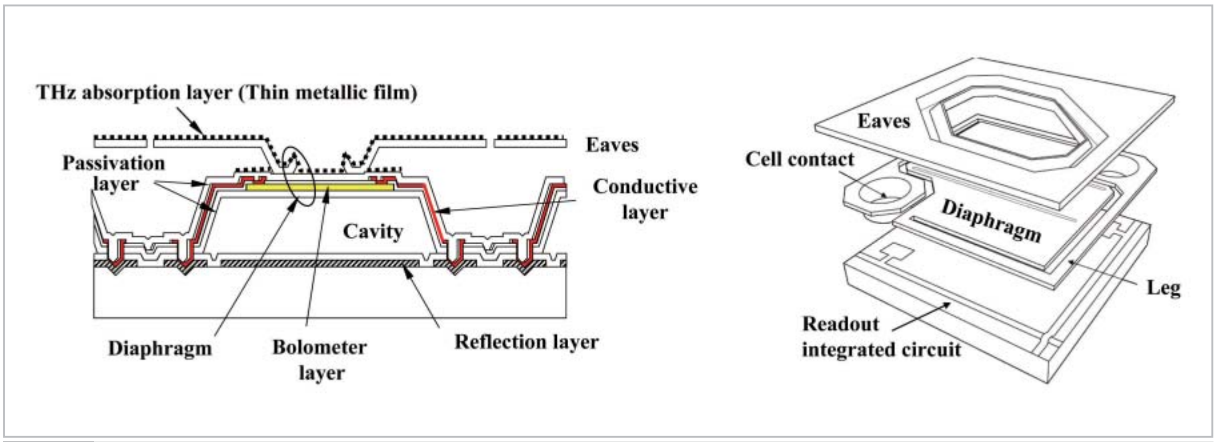

Fig.5 *Pixel structure of 320 × 240 VOx uncooled terahertz focal plane array sensor*

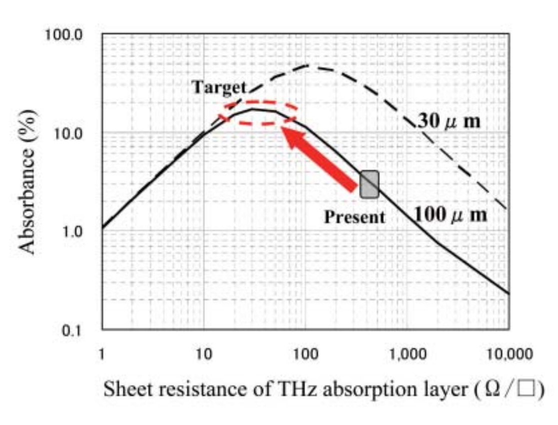

Fig.6 *Absorption characteristics of optical resonance structure of terahertz waves*

Solid line: wavelength of 100 μm (3 THz); broken line: wavelength of 30 μm (10 THz)

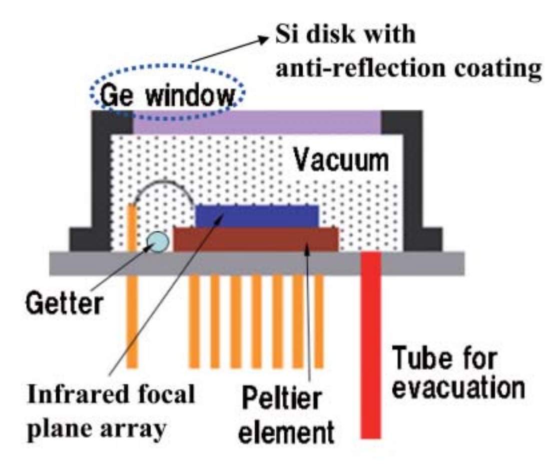

Fig.7 *Schematic diagram of vacuum package window of array sensor*

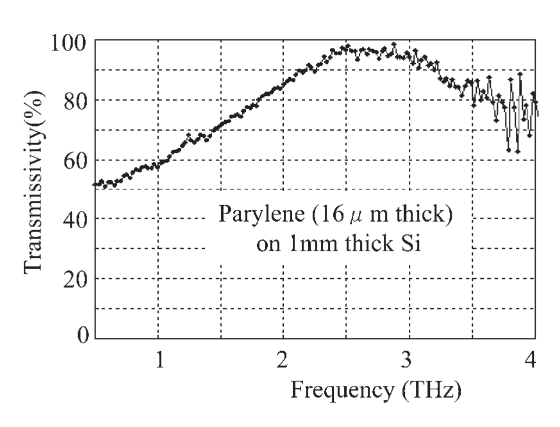

Fig.8 *Transmission characteristics of window material fabricated by depositing parylene (16-μm thick) on both sides of high-resistance Si*

without significantly modifying the present pixel structure[7]. As the figure shows, a newly incorporated improvement in detecting terahertz waves is seen in the terahertz absorption film, comprised of a metal thin film, indicated by the dotted line on the diaphragm and the eaves. When a metal thin film is formed to cover the locations indicated, it causes optical interference with the reflection film on the Si read-out integrated circuit, resulting in resonance absorption (i.e., an optical resonance structure). To date, there has been much study of absorption by a metal thin film structured with a cavity and a reflection film. Here, we use Equation (1), taken from a paper by K. C. Liddiard[8]. Figure 6 shows the absorption characteristics calculated with varying sheet resistance in the metal thin film (i.e., the terahertz absorption film), for the wavelength of 30 μm (10 THz) and 100 μm (3 THz), with a cavity height of 1.5 μm and a sheet resistance of 0.09 Ω for the reflection film. As the figure shows, when the sheet resistance of the metal thin film is set from 20 Ω to 60 Ω, the responsivity at a wavelength of 100 μm is expected to improve by nearly an order of magnitude compared to the present performance.

Next, high-resistance Si covered with anti-reflection coating is a promising candidate for improving the transmittance of the vacuum package window material of the array sensor in the terahertz range[9]. Figure 7 shows a schematic diagram of the vacuum package of the array sensor. In the 10-μm wavelength range, Ge is the most suitable material. However, as discussed earlier, the transmittance of this material is extremely low at 3 THz, 30 % or less. To improve this characteristic, we deposited a 16-μm thick parylene coating on both sides of a high-resistance Si wafer, which led, as anticipated, to a high transmission value (Fig. 8)—over three times larger than the terahertz transmittance of the present Ge window. In the future, we plan to use high-resistance Si coated with parylene on both sides of the vacuum package window.

3 Conclusions

The authors have succeeded in real-time imaging of THz line emission from QCL — a first for Japan — using an uncooled infrared focal plane array. Based on the results of this experiment, we derived the quantitative performance of the present array sensor. This article also describes some ideas for improving the responsivity of this array sensor in the terahertz range and shows the results of technological development of the window material.

In developing terahertz remote imaging technology that will prove useful at the sites of natural or other disasters, it is extremely important for system design to acquire spectroscopic data for atmospheric absorption and for living bodies, as well as to ensure the technological development of the required terahertz sources, array sensors, and cameras. In the future, we will expand current databases in addition to developing the requisite hardware, working toward the success of the overall sponsored research.

The achievements of this research project are obtained under the auspices of a NICT sponsored research and development project relating to advanced communications and broadcasting technologies. We are sincerely grateful for the research opportunities this project has provided.

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Condensed Matter Physics