COMPACT TWO-DIMENSIONAL ARRAY OF STRESSED GE:GA DETECTORS

Y. DOI
College of Arts and Sciences, University of Tokyo
Komaba 3-8-1, Meguro, Tokyo 153-8902, Japan

S. MAKIUTI, H. OKUDA AND T. NAKAGAWA
The Institute of Space and Astronautical Science
Yoshinodai 3-1-1, Sagamihara, Kanagawa 229-8510, Japan

H. SHIBAI AND M. KAWADA
School of Science, Nagoya University
Furo-cho, Chikusa, Nagoya 464-8602, Japan

AND

N. HIROMOTO, M. FUJIWARA AND K. OKUMURA
Communications Research Laboratory
Nukui-kita 4-2-1, Koganei, Tokyo 184-8795, Japan

Abstract. We have developed a 4×8 array of stressed Ge:Ga detectors. This array detector has a high density format of entrance pupils so that we can minimize the size of the camera optics. The cutoff wavelength of the detector is about 170 μm, and the detector's NEP is better than 10^{-16} W Hz$^{-1/2}$. We are going apply this array detector to balloon-borne astronomical observations. Furthermore, we are developing this detector into a 5×15 array detector that will be placed onboard the IRIS satellite to be launched in 2003.

Key words: far-infrared detector array, infrared survey

1. Introduction

Ge:Ga photoconductors are at present the most sensitive detector for far-infrared radiation in the wavelengths between 50 and 200 μm. The cutoff wavelength is about 100 μm in unstressed condition but it can be extended by applying mechanical stress to the detector chip. The degree of the extension depends on the applied stress. When a detector chip is stressed by a pressure of 700 $\mathrm{N\,mm^{-2}}$, which is nearly the practical yield stress of a Ge:Ga chip, the cutoff wavelength increases to 200 μm (see for example, Hiromoto *et al.*, 1989).

Two-dimensional arrays of this type of detector are currently being used for various projects (see for example, Stacey *et al.*, 1992; Young *et al.*, 1995; Clegg *et al.*, 1996; Lemke *et al.*, 1996; Erickson *et al.*, 1996; Kawada, 1998).

In this paper, we describe the development of 2-d array of stressed Ge:Ga detectors that are to be applied to balloon and satellite observations.

2. Detector Development

2.1. DESIGN GOAL

Because reduction of FPI size is important for balloon and satellite applications, the following three conditions have been imposed on the detector design: 1) the physical size of the detector mount must be compact, 2) the pixel size of the detectors must be small so that the focal length of the camera optics can be shortened, and 3) the entrance pupils of the detectors must be densely arranged so that the optical path of the camera optics can be narrowed.

2.2. STRUCTURE OF THE ARRAY DETECTOR

We made a compact linear-array of stressed Ge:Ga detectors. Then we developed this linear array into a two-dimensional array by arranging several linear-arrays in parallel. Thereby, we have constructed a prototype 4×8 array of stressed Ge:Ga detectors that satisfies the requirements described in §2.1.

In the followings, we describe the structure of these array detectors.

2.2.1. *Stressing Mechanism*

The structure of the stressing mechanism is shown in Figure 1. Conical spring washers are used as a spring to stress Ge:Ga chips (Hiromoto *et al.*, 1989). We can adjust the stress precisely by using this spring, and we can reduce the pressure change to less than 20% over a thermal cycle between room temperature and 2 K. The volume efficiency of the spring is higher than those of other springs. The required stress (as large as 700 N) can be easily provided in a small volume (ϕ 5.4 mm; see Figure 1).

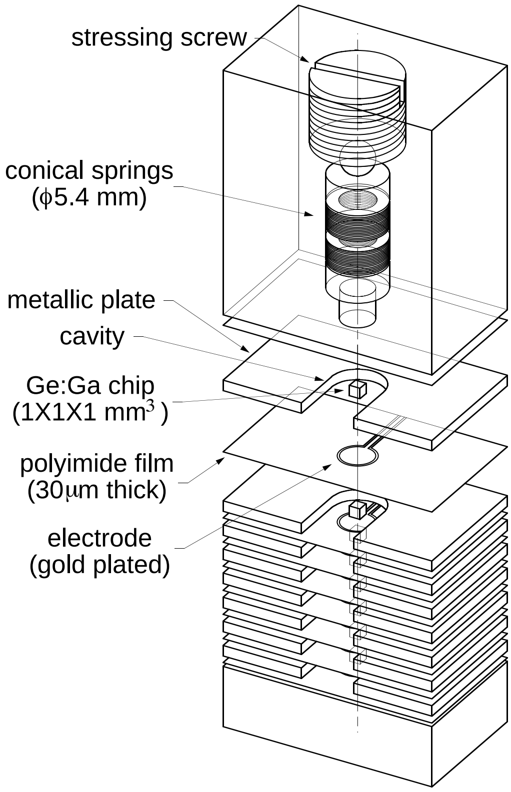

Figure 1. A schematic drawing of the stressing mechanism and the linear array detector

2.2.2. *Simultaneous Stressing of a Linear Array of Detector Chips*

In order to make a compact detector, we must place the detector chips as close as possible to each other. Therefore, we stack the detector chips ($1\times1\times1$ mm^3) and apply stress to the chips simultaneously by using a single piston (Figure 1, see also Hiromoto *et al.*, 1992). Thin films of polyimide (30-μm thick) are placed between the chips for electrical insulation. Electrode patterns are printed on both sides of the films in order to read out electric signal from the detector chips.

By stacking the detector chips with a positional accuracy of 20 μm, we succeeded in stressing a linear array of 8 elements (Shibai *et al.*, 1994).

2.2.3. *Cavity with Light Pipe*

Next, we designed a two-dimensional array by arranging several linear-arrays in parallel.

To minimize the size of the detector mount, we need to make the spacing

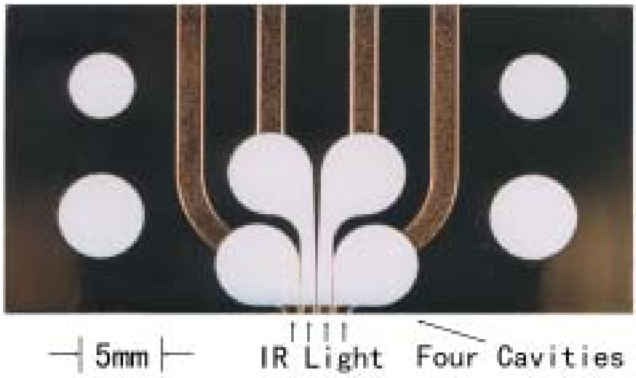

Figure 2. Four cavities drilled through a metallic plate

between detector rows as small as possible. However, we cannot reduce this spacing to less than about 5 mm because of the size of the stressing mechanism (see Figure 1). We also need to arrange the entrance pupils as close to each other as possible (§2.1).

Thus we connected the entrance pupil to the cavity with a light pipe whose cross section was 0.9×0.9 mm^2.

We tested the collecting efficiency of the light pipe and found that there was no degradation in efficiency as long as the light pipe was straight and its length was less than about 5 mm.

Based on this result, we designed a cavity plate with four cavities machined on a metallic plate as shown in Figure 2.

2.2.4. *Assembling a Two-dimensional Array*

We place detector chips at the center of each cavity with a positional accuracy of 20 μm. Each chip was fixed to the electrode film with electroconductive adhesive. We stacked 8 plates of these detector sets and aligned them using knocking pins so that the detector chips of each line were in a straight line.

The completed detector mount is shown in Figure 3. The entrance pupils (0.9×0.9 mm) are separated from each other by thin walls of 0.1 mm thick. The pupils are thus arranged in 1 mm pitch and as the result, the focal plane of the detector is very compact. Two out of four sets of stressing mechanisms are held in the block above the piled plates and the other two sets are held in the block below the piled plates, so that we can stress four lines of detector chips.

We were able to apply a maximum stress of 600 N mm^{-2} to the detector chips.

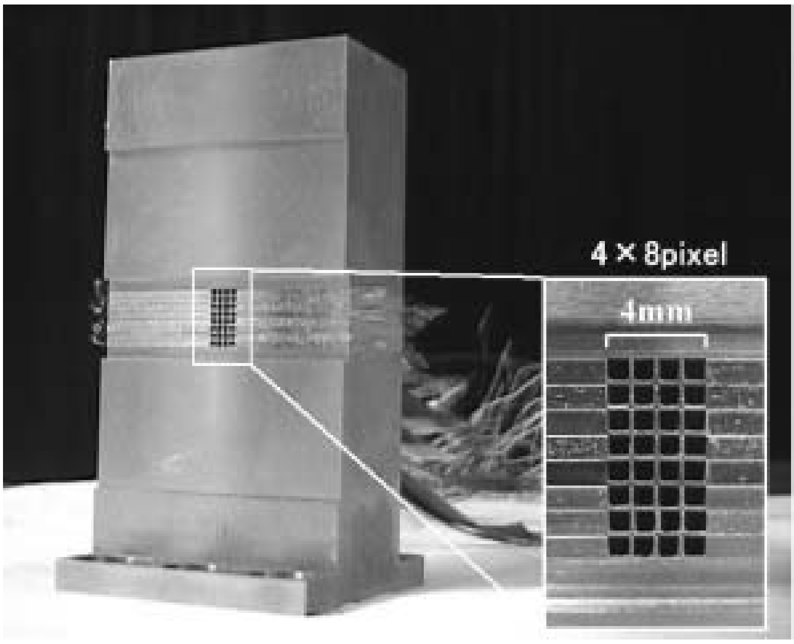

Figure 3. The assembled 4×8 array detector

This maximum stress is somewhat smaller than the practical yield stress of Ge:Ga chip (700 $\mathrm{N\,mm^{-2}}$: see §1). Positional accuracy (20 μm for this detector set; see above) is the main factor in limiting the maximum stress.

2.3. THE PERFORMANCE OF THE DETECTOR

In this section, we describe spectral response, responsivity, and noise equivalent power (NEP) of the detector. We apply a stress of 600 $\mathrm{N\,mm^{-2}}$, as described above. We used trans-impedance amplifier (TIA) for a readout circuit. Feedback resistances were 100 MΩ. The measurement conditions and results are summarized in Table 1.

The spectral response is shown in Figure 4. Cutoff wavelengths were about 170 μm, and the spectral responses were almost identical for all the detectors. Our measurement showed that the detector response was 47 ± 12 $\mathrm{A\,W^{-1}}$. Both the spectral responses and the detector responses showed no dependence on pixel location in the array. Although the measurement accuracy was limited by noise of the readout circuit, we found that the detector NEP was better than 10^{-16} $\mathrm{W\,Hz^{-1/2}}$.

TABLE 1. Detector performance measurement conditions

Parameter	Value
Applied bias voltage [mV].......	30
Applied bias field [V cm^{-1}].....	0.3
Background flux [W]...........	1.1×10^{-9}
Background photon rate [s^{-1}]...	8.6×10^{11}
Signal flux [W]..................	7.2×10^{-12}
Signal photon rate [s^{-1}]........	5.6×10^{9}
Signal modulation frequency [Hz]	22
Detector temperature [K].......	1.8–2.0
Detector DC output [V].........	9.1 ± 1.0
Detector AC output [mV].......	30.5 ± 6.4

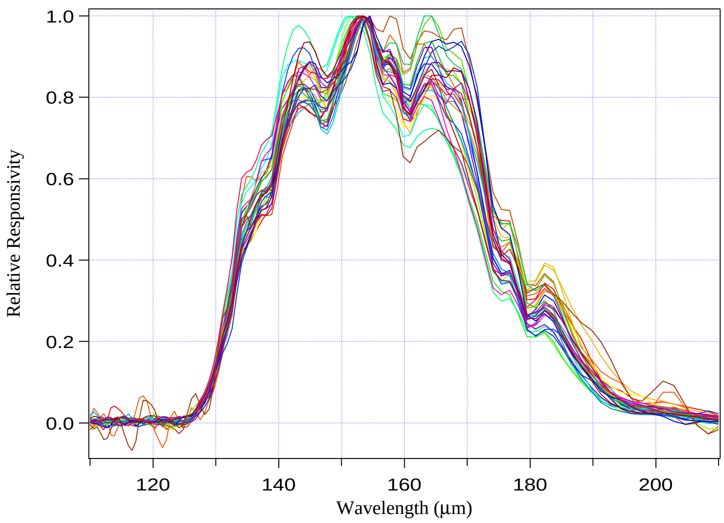

Figure 4. Spectral responses of the 4×8 detectors. Note that the response shorter than about 140 μm is eliminated by a low-pass filter.

3. Applications

We plan to apply this 4×8 array detector to balloon-borne astronomical observations. For this purpose, we have developed a balloon-borne telescope system that carries a 50-cm telescope (Doi *et al.*, 1999). Emissivity of the telescope is expected to be on the order of 10^{-2}, so that we can suppress

TABLE 2. A summary of the FIS onboard the IRIS

FPI	Far-Infrared Surveyor (FIS)			
detector	unstressed Ge:Ga		stressed Ge:Ga	
wavelength(μm)	50 – 100	50 – 75	100 – 200	150 – 200
dimension	3×20	2×20	3×15	2×15
pixel size	30"		50"	
observation modes	all sky photometric survey Fourier spectroscopy			

background photon noise to as low as 1 Jy (per 1 pixel, 1 sec integration).

We will mount the 4×8 array detector on the telescope and carry out a photometric survey at the wavelength of 160 μm with a spatial resolution of $1.5'$. The sensitivity of this survey will be limited by the background photon noise. We can survey an area of the sky up to 100 deg^2 in one balloon flight.

The first observational flight is scheduled in Nov. 1999, and several consecutive flights in the following years are planned.

4. Further development

4.1. IRIS PROJECT

On the basis of our experience with the 4×8 array detector, we are now developing a 5×15 detector array to be aboard the IRIS (InfraRed Imaging Surveyor: Astro-F) satellite (Murakami, 1998).

The IRIS is a Japanese astronomical satellite that will be launched in 2003. The telescope on the IRIS has a 70-cm diameter, and two focal plane instruments (FPIs) will be placed onboard: the InfraRed Camera (IRC: Matsuhara, 1998) and the Far-Infrared Surveyor (FIS: Kawada, 1998). Unstressed and stressed Ge:Ga detectors are to be used for the FIS and with these detectors, we will carry out a whole sky survey as well as spectroscopic observations. Specifications of the FIS are summarized in Table 2.

4.2. STRESSED GE:GA ARRAY DETECTOR FOR THE IRIS

The structure of the 5×15 array for the IRIS is basically the same as that of the 4×8 array (Figure 5). Five cavities with detector chips are distributed in one plate. Three out of the five detectors are used for the 100–200 μm band and the remaining 2 detectors are for the 150–200 μm band (see also Table 2).

Figure 5. Conceptual design of five cavities distributed on a metallic plate

We plan to use capacitive trans-impedance amplifier (CTIA) for a read out circuit. MOS-FETs will be integrated in bare-chips, and the chips will be mounted in a detector housing. The circuits will be operated at temperatures under 2 K. We are now developing the CTIA IC. It's development will be completed by the end of 1999 (Noda *et al.*, 1998).

For space applications of the detector, we must consider effects such as influence of high-energy radiation as well as how the detector behaves in a low photon background (see for example, Haller, Hueschen, and Richards, 1979; Oda *et al.*, 1984; Hiromoto *et al.*, 1992; Hiromoto *et al.*, 1996; Shibai *et al.*, 1996). We plan to make pre-flight tests to measure these effects.

We plan to develop this array detector in the next two years.

5. Summary

We have developed a 4×8 array of stressed Ge:Ga detectors. This array detector has 4×8 entrance pupils, each measuring 0.9×0.9 mm^2 with a 1-mm pitch, so that we can minimize the size of camera optics. The cutoff wavelength is about 170 μm, and detector's noise equivalent power (NEP) is better than 10^{-16} W Hz$^{-1/2}$. We are going to use this array detector with a balloon-borne telescope to carry out photometric surveys of the far-infrared sky. Furthermore, we are developing a 5×15 array detector that will be placed aboard the IRIS satellite to be launched in 2003.

References

Clegg, P.E., *et al.* (1996) The ISO Long-Wavelength Spectrometer, *Astron. Astropys.*, **315**, L38

Doi, Y., Okuda, H., Nakagawa, T., Kawada, M., Kaneda, H., Makiuti, S., Morimoto, H., Narita, M., Shibai, H., Arimura, S., and Okumura, K. (1999) A new Japanese infrared balloon telescope, proc. of the 32nd COSPAR Scientific Assembly, submitted to *Advances in Space Research*

Erickson, E. F., Haas, M. R., Baltz, J. A., Colgan, S. W. J., Lynch, D. H., Mckelvey, M. E., and Wolf, J. (1996) Farinfrared detector arrays for a SOFIA Echelle Spectrometer, Proc. 30th ESLAB Symp. *Submillimeter and Far-Infrared Space Instrumentation*, ESA **SP-388**, 21

Haller, E. E., Hueschen, M. R., and Richards, P. L. (1979) Ge:Ga photoconductors in low infrared backgrounds, *Appl. Phys. Lett.*, **34**(8), 495

Hiromoto, N., Itabe, T., Aruga, T., Okuda, H., Matsuhara, H., Shibai, H., Nakagawa, T., and Saito, M. (1989) Stressed Ge:Ga photoconductor with a compact and stable stressing assembly, *Infrared Phys.*, **Vol. 29**, 255

Hiromoto, N., Itabe, T., Shibai, H., Matsuhara, H., Nakagawa, T., and Okuda, H. (1992) Three-element stressed Ge:Ga photoconductor array for the infrared telescope in space, *Appl. Opt.*, **Vol. 31**, 460

Hiromoto, N., Fujiwara, M., Shibai, H., and Okuda, H. (1996) Ge:Ga far-infrared photoconductors for space applications, *Jpn. J. Appl. Phys.,* **35**, 1676

Kawada, M. (1998) FIS: Far-Infrared Surveyor onboard IRIS, in *Infrared Astronomical Instrumentation*, A. M. Fowler, ed., *Proc. SPIE* **3354**, 905

Lemke, D. *et al.* (1996) ISOPHOT–capabilities and performance, *Astron. Astrophys.*, **315**, L64

Makiuti, S., Okuda, H., Nakagawa, T., Kawada, M., Doi, Y., Shibai, S., Hiromoto, N., and Okumura, K. (1998) Development of stressed Ge:Ga 2D array, in *Infrared Astronomical Instrumentation*, A. M. Fowler, ed., *Proc. SPIE* **3354**, 261

Matsuhara, H. (1998) IRC: An Infrared Camera onboard the IRIS, in *Infrared Astronomical Instrumentation*, A. M. Fowler, ed., *Proc. SPIE* **3354**, 915

Murakami, H. (1997) IRTS mission overview, in *Diffuse Infrared Radiation and the IRTS*, H. Okuda, T. Matsumoto, T. Rollig, eds., *ASP Conf. ser.* **124** 13

Murakami, H. (1998) Japanese Infrared Survey Mission IRIS (ASTRO-F), *in Space Telescope and Instruments V*, P. Y. Bely and J. B. Breckinridge, eds., *Proc. SPIE* **3356**, 471

Noda, M., Shibai, H., Watabe, T., Hirao, T., Yoda, H., Nagata, H., Nakagawa, T., and Kawada, M. (1998) Evaluation of charge integrating amplifiers with silicon MOSFETs for cryogenic readout, in *Infrared Astronomical Instrumentation*, A. M. Fowler, ed., *Proc. SPIE* **3354**, 247

Oda, N., Lemke, D., and Wolf, J. Radiation effects on a Ge:Ga far-infrared photoconductive semiconductors, *Int. J. IR and Millimeter Waves* **5**, 1449

Shibai, H., Okuda, H., Murakami, H., Nakagawa, T., Hiromoto, N., Fujiwara, M., Kawamata, H., Okumura, K., and Makiuti, S. (1994) An eight-element stressed Ge:Ga linear array: development and performance, in *Infrared Spaceborne Remote Sensing II*, M. S. Scholl, ed., *Proc. SPIE* **2268**, 142

Shibai, H., Nakagawa, T., Makiuti, S., Matsuhara, H., Hiromoto, N., Okumura, K., Doi, Y., Toya, T., and Okuda, H. (1996) Flight Performance of the Far-Infrared Line Mapper (FILM), in *Infrared Spaceborne Remote Sensing IV* M. S. Scholl and B. F. Andersen, eds., *Proc. SPIE* **2817**, 267

Stacey, G. J., Beeman, J. W., Haller, E. E., Geis, N., Poglitsch, A., and Rumitz, M. (1992) *Int. J. IR and Millimeter Waves* **13**, 1689

Young, E., Scutero, M., Rieke, G. H., and Davis, J. (1995) Construction of the large-format far-infrared array for SIRTF, in Infrared Detectors and Instrumentation for Astronomy A. M. Fowler, ed., *Proc. SPIE* **2475**, 441