LARGE-FORMAT AND COMPACT STRESSED GE:GA ARRAY FOR THE ASTRO-F (IRIS) MISSION

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ABSTRACT

We describe the development of a stressed Ge:Ga array detector with a large pixel format but a compact mechanical structure. The detector will be deployed in IRIS, a Japanese satellite to be launched in 2004, which will conduct an all-sky, far-infrared survey as well as spectroscopic observations of specific objects. The array has a 5×15 pixel format. Three of the five rows are for the $100 - 200$ μm band, and the other two are for the $150 - 200$ μm band. In the focal plane of the IRIS telescope, each pixel corresponds to a field of view of 50" $\times$ 50". A uniaxial mechanical stress is applied to the detector chips in each row using a single stressing mechanism. This results in a compact focal-plane array. Light pupils of 0.9×0.9 mm size are distributed with a pitch of 1 mm. A capacitative trans-impedance amplifier (CTIA) circuit is used as the readout. Bare-chip amplifiers and multiplexers are placed behind the Ge:Ga chips and are cooled to 1.8 K. The entire system, including chips and readouts, weighs 300 grams. We have thus succeeded in building a compact array detector suitable for a satellite payload.

INTRODUCTION

The stressed Ge:Ga detector is a sensitive detector for far-infrared light in the $100 - 200$ μm band. We are developing a stressed Ge:Ga detector array to deploy in the Astro-F (IRIS), a Japanese satellite for infrared astronomy to be launched in 2004. By using this satellite, we will conduct an all-sky, far-infrared survey as well as spectroscopic observations of specific objects (Shibai, 2000; Takeuchi, et al., 2000).

For deployment in the satellite, we need to consider the following requirements in building the detector:

- Large pixel format and high sensitivity to survey a wide area of the sky effectively,
- Lightweight and compact structure to be placed in a satellite of finite area and weight,
- Compact focal plane to minimize the size of the camera optics.

By considering the above requirements, we develop a detector array with the following characteristics:

- Large format: 5×15 pixels,
- High sensitivity: 17.3 ± 0.4 A/W,
- Compact and lightweight structure: focal plane size 9×15 mm, detector size $40 \times 50 \times 70$ mm, and total weight 300 g.

In this paper, we describe the structure of the detector and its performance.

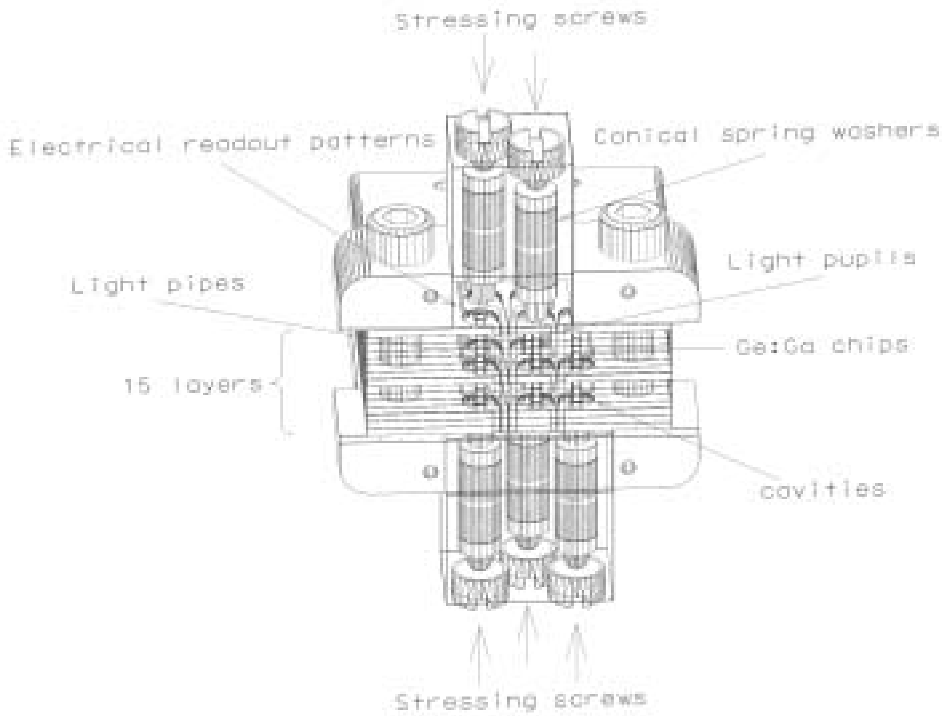

Fig. 1. A schematic drawing of the Ge:Ga detector array. Light pupils are distributed on the focal plane of the detector in an array of five by fifteen (see also Figure 2). Three rows of fifteen pupils are for the 100 – 200 μm band (wide band) and 2 rows of 15 pupils are for the 150 – 200 μm band (narrow band). A mechanical stress is applied to a row of 15 detector chips by a stressing mechanism that consists of conical spring washers and a stressing screw. Two stressing mechanisms are installed in the upper block, and three are installed in the lower block.

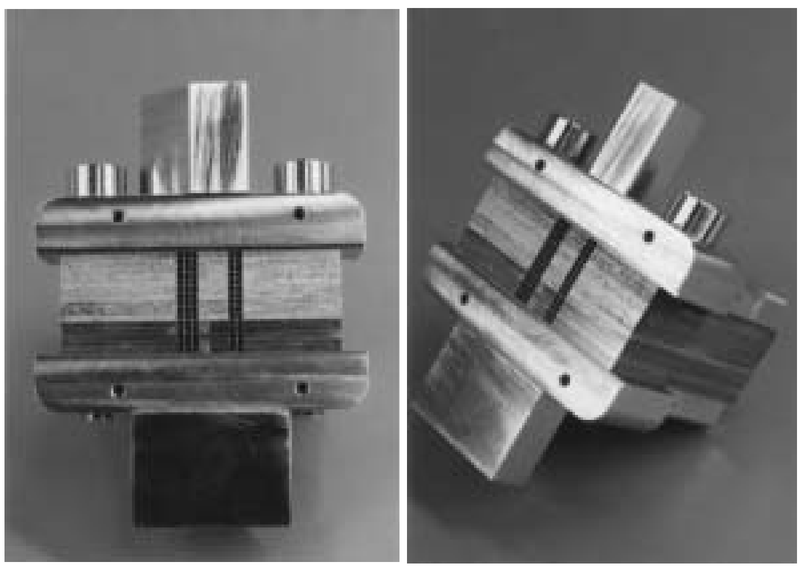

Fig. 2. Photographs of the detector.

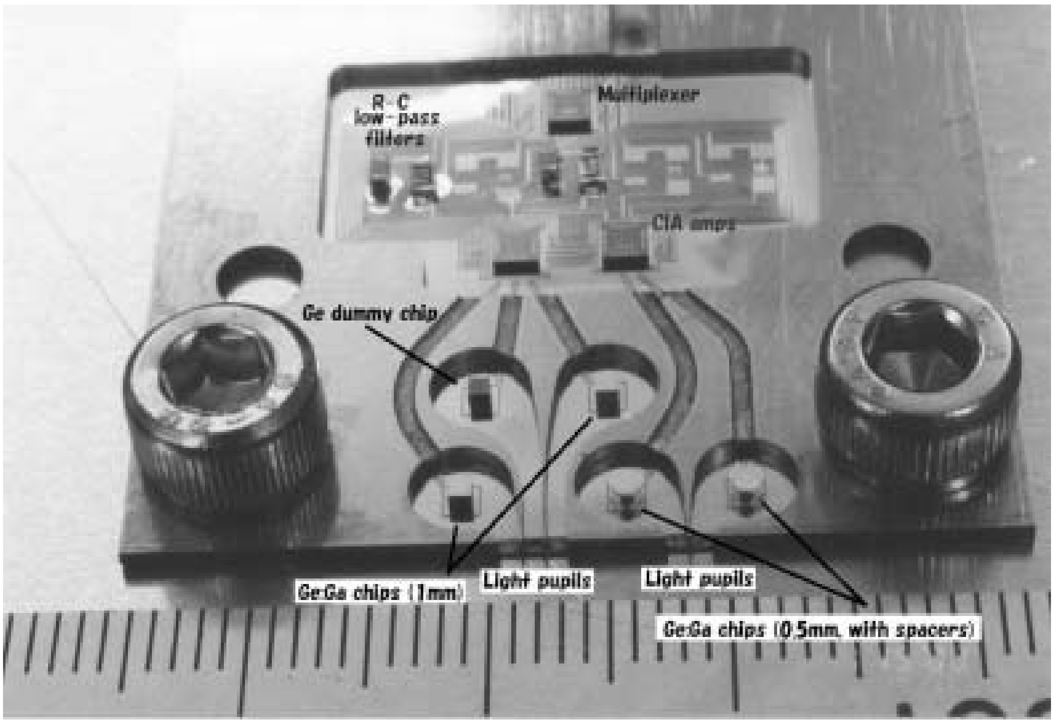

Fig. 3. One layer of the PM. Detector chips are distributed in the cavities. Two sizes of chips are used. The readout electronics (amplifiers and a multiplexer) are placed behind the chips.

DETECTOR STRUCTURE

We show the structure of the detector in Figure 1.

The detector chips are made of Ge:Ga. Each chip is installed in a cavity, in which the incident far-infrared light is captured and then absorbed by the chip.

Polyimide sheets are placed on both the top and bottom of the cavities and hold the detector chips. Electrical readout patterns are printed on both sides of the sheets, and we read out the electrical signal from the detector chips through these patterns.

To make a Ge:Ga detector sensitive to far-infrared light of 100 – 200 μm, we need to apply a mechanical stress to the detector chips. The stress is uniaxial and about 400 N mm^{-2}.

We use conical spring washers to stress the detector chips. By using springs, we can adjust the stress accurately and keep it stable during thermal cycles. Using conical spring washers is also beneficial because they are compact but can generate enough force for stressing.

We stress each row of 15 detector chips using one stressing mechanism. We place chips in a straight line and apply the stress to all the chips along the line. By using this stressing method, we can reduce the number of stressing mechanisms in a detector set. This enables us to minimize the size of the detector.

Far-infrared light incident on the light pupils on the focal plane of the detector is transmitted to the cavities through light pipes. By using these pipes, we can place the light pupils adjacently. The pupils are distributed with a 1-mm pitch, and the total size of the plane is 15×9 mm. This compact focal plane size enables us to minimize the size of the camera optics and thus the size of the focal plane instrument in which the detector is installed. The pupil size is 0.9×0.9 mm, and the optical filling factor is more than 80%.

Structure of the Prototype Detector

We built a Prototype Model (PM) of the detector to test its performance and check the construction procedure. Photographs of the PM detector are shown in Figure 2.

Two sizes of detector chips were used for the PM (see Figure 3). One was $1 \times 1 \times 1$ mm, and the other

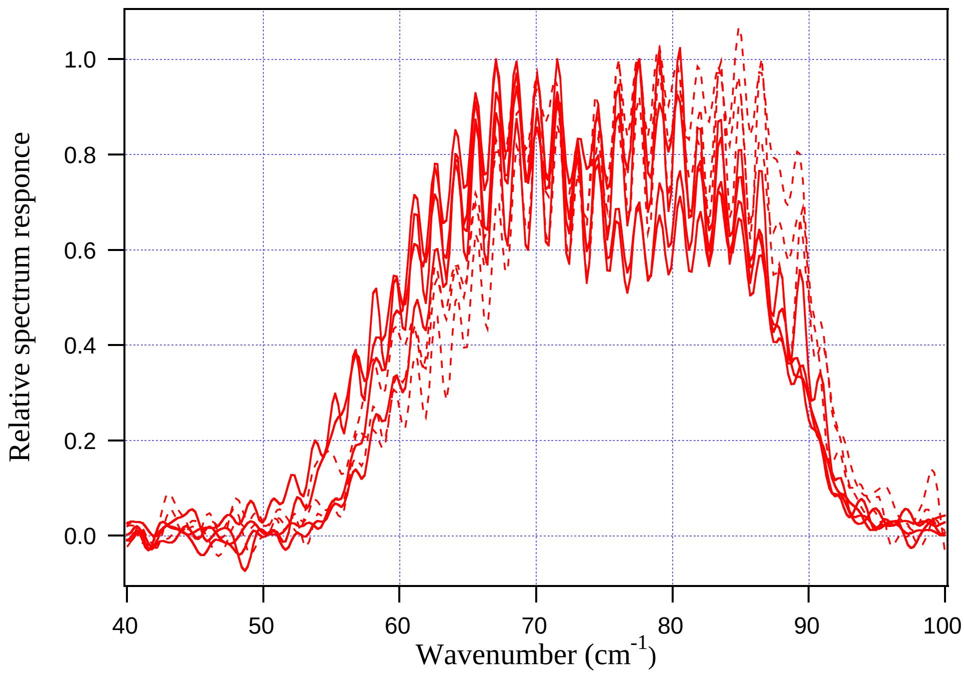

Fig. 4. Spectrum responses of the seven measured detector chips. The solid lines are the responses of the 1-mm chips, and the dotted lines are those of the 0.5-mm chips. The spectrum dips around 72 cm^{-1} are due to absorption by a vacuum window (polyethylene film). Wavelengths shorter than about 90 cm^{-1} are eliminated by a low-pass filter.

was 0.5 × 0.5 × 0.5 mm.

For the smaller detector chip, we expect a larger photoconductive gain because of the lower possibility of recombination of photo-excited holes. In addition, we expect a lower possibility of cosmic ray hits during observation with the smaller chip because of its smaller collision cross section. On the other hand, we need greater positional accuracy for the smaller chips to apply the mechanical stress properly.

To decide which chip size should be used for the Flight Model (FM) detector, we tested the two sizes and compared their performance.

Figure 3 is a photograph of 1 of the 15 layers of the PM detector. Five detector chips were installed in the cavities. Two of them are 1- mm chips, and another two are 0.5-mm chips. The remaining chip is a Ge dummy (non-detector) chip used to check construction procedure. Thin metallic sheets (0.2-mm thick, made of phosphorus bronze) were placed on the tosp and bottoms of the 0.5-mm chips to match their heights to the 1-mm chips.

We used a flip-chip bonder to adjust the positions of the detector chips with an accuracy better than 1% of the chip size. The chips were fixed to the polyimide film, on which the electrodes were printed, using an electro-conductive adhesive.

PERFORMANCE OF THE PROTOTYPE DETECTOR

Detectivity

We built 15 detector layers like that shown in Figure 3. Before we could stack them and apply stress, however, one of the chips came off by accident. Therefore, we proceeded with the test using 14 layers.

We gradually stressed the detector chips, and successfully applied a stress of 400 N mm^{-2} for both the 0.5- and 1-mm chips.

We cooled this detector set down to 1.8 K and measured the detectivity and wavelength response. For this test, we used a trans-impedance amplifier (TIA) circuit to read out the detector signal.

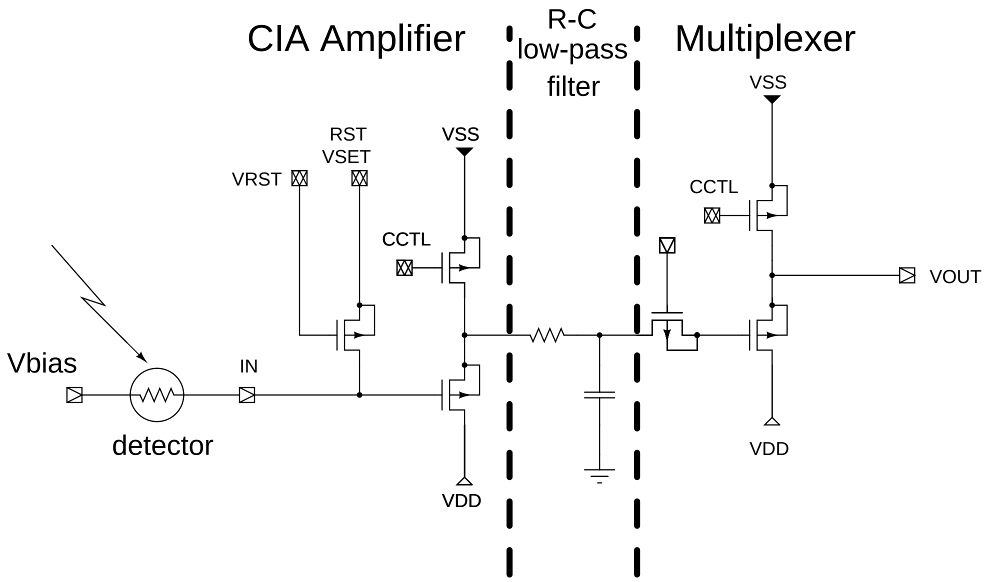

Fig. 5. The configuration of a CIA circuit applied for the PM detector. The photo-current from the detector is integrated to a capacitance between the input gate and source of a field effect transistor (FET). The circuit is a source follower, producing an output signal with low impedance. A multiplexer is used to select one of five channels in a detector layer. An R-C low pass filter is placed between the amplifier and the multiplexer to prevent alias noise from affecting the output signal.

We selected seven detector chips for the test. The measured detectivities were 17.3 ± 0.4 A/W for the 1-mm chips (bias voltage 30 mV) and 12.9 ± 1.6 A/W for the 0.5-mm chips (bias voltage 20 mV) at a photon influx of 8×10^{10} photons/s. The detectivity of the 1-mm chips were about double that of the 0.5-mm chips. This is because the spacers on the tops and bottoms of the 0.5-mm chips limited effective absorption of incident far-infrared light by the detector chips.

As for the light pipes, we found no degradation in their efficiency due to the length of the pipes. We thus confirmed that using light pipes is effective for arranging a focal plane more compactly.

The spectrum responses of the seven chips are shown in Figure 4. We found no significant difference in spectrum responses between the chips. We thus concluded that the stress was applied uniformly to the detector chips.

Signal Readout by Cooled Electronics

As for the readout electronics of the FM detector, we will use a newly developed capacitative trans-impedance amplifier (CTIA) circuit (Hirao, et al., 2000). We will put a bare-chip integrated circuit behind the detector chips and will cool both the electronics and the detector chips down to 1.8 K.

To test this configuration, we applied the prototype electronics in the PM detector shown in Figure 3. A charge integration amplifier (CIA) is used for the PM detector. The configuration of the PM circuit is shown in Figure 5.

We tested one detector layer with the CIA readout circuit. Five 0.5-mm detector chips were used. No mechanical stress was applied to these detectors. We show examples of the detected signals in Figure 6. As shown in the figure, the photocurrent from the detectors was properly integrated, and thus we confirmed that the circuit works correctly.

FM CONSTRUCTION

Based on the test results described above, we are going to construct the FM detector. Construction will start in November 2000, and we will complete development by February 2001.

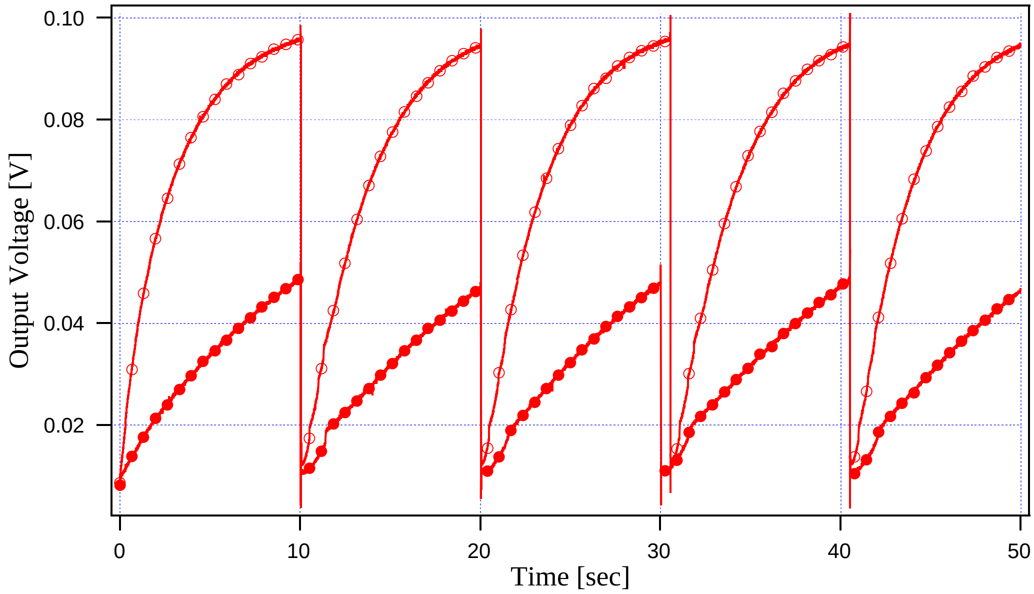

Fig. 6. An example of output signals read by the cooled CIA circuit. The lines with open circles represent data for when a black body installed in the cryostat is on and 30-K black-body radiation (1.1×10^6 photons/s) is incident on the detector. The photo-excited electronic charge is integrated and then reset at 10-sec intervals. The lines with closed circles represent data for when the black body is off.

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