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GE:6A PHOTOCONDUCTORS IN LOW INFRARED BACKGROUNDS, (U)

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6 Ge:Ga Photoconductors in Low Infrared Backgrounds,

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Abstract

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We report the development of infrared photoconductive detectors which are background fluctuation noise limited at photon fluxes $\leq 10^8 \text{ s}^{-1}$. The detectors were fabricated from germanium doped with $2 \times 10^{14} \text{ cm}^{-3}$ gallium. Detectors operated in the conventional manner at $T = 3 \text{ K}$ showed significant photoconductive response for wavelengths out to $120 \text{ } \mu\text{m}$ with a minimum NEP of $2.4 \times 10^{-17} \text{ W Hz}^{-\frac{1}{2}}$ at $94 \text{ } \mu\text{m}$. Detectors operated at $T = 2 \text{ K}$ with a uniaxial stress of 60 kgf mm^{-2} applied along a [100] direction showed significant response to $205 \text{ } \mu\text{m}$ and gave a minimum NEP of $5.7 \times 10^{-17} \text{ W Hz}^{-\frac{1}{2}}$ at $\approx 150 \text{ } \mu\text{m}$. The stressed detectors are four orders of magnitude more sensitive than any previous photoconductor beyond $120 \text{ } \mu\text{m}$.

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~~We report~~ photon noise limited performance of photoconductive detectors made from gallium doped germanium in very low infrared backgrounds ($\leq 10^8$ incident photons per second). ^{IS REPORTED IN THIS REPORT} These detectors were made from a large volume crystal of Ge:Ga of the quality used for lithium drifted germanium gamma-ray spectrometers. This material contained very low concentrations of deep traps and minority impurities (mainly phosphorus). These conditions were made possible by the use of high purity Ge crystal growing equipment. ¹ The detector contacts were made by implanting boron ions. Such contacts have been shown to be superior to any other type of contact to p-type Ge at low temperatures. ² The Ga concentration of $2 \times 10^{14} \text{ cm}^{-3}$ was chosen small enough to avoid impurity banding effects. Because the optical absorption lengths are longer than the device dimensions at this doping level, the best performance is obtained in an integrating cavity. When operated in the conventional way, ³ Ge:Ga photoconductors give significant response out to 120 μm . The application of a large uniaxial stress along a [100] crystallographic axis reduces the binding energy of group III impurities to $\approx 6 \text{ meV}$ and thus shifts the threshold of the detector to longer wavelengths. ^{4,5} With a uniaxial stress of 60 kgf mm^{-2} , significant photoconductive response is seen out to 205 μm .

This detector development was motivated by the needs of space astronomy projects using cooled optics, such as the infrared astronomical satellite (IRAS), the cosmic background explorer satellite (COBE), the far infrared sky survey experiment (FIRSS), and the shuttle infrared telescope facility (SIRTF). The conditions of these experiments are such that detectors are required which approach photon noise limited operation at very low infrared background levels.

The unstressed detectors were made by cutting 1.0 and 1.5 mm thick wafers perpendicular to the crystal growth axis. The wafers were lapped with 1900 mesh grit, chemically polished with a 4:1 mixture of $\text{HNO}_3:\text{HF}$ until all damage

was removed, and rinsed with methanol. Implantation of B^+ ions formed p^+ contacts on both faces. Doses of 10^{14} ions/cm² at 25 keV and 2×10^{14} ions/cm² at 50 keV were implanted to provide a roughly square step doping profile about 2000 Å thick. The wafers were annealed for 30 minutes at 200°C in argon to remove implantation damage and to activate the boron. A 1 μm layer of gold was sputtered onto the p^+ contact surfaces. Detectors with dimensions of 1 × 1 × 3 mm were cut with a wire saw. The four bare surfaces of each detector were chemically polished as described above. Pure indium solder was used to mount the detectors on 6 mm lengths of 1 mm diameter steel drill rod.

The stressed detectors were 1 × 1 × 6 mm rectangular parallelepipeds. The long dimension, along which the stress was to be applied, was aligned within one degree of a [100] axis. The 1 × 1 mm ends were lapped perpendicular to the 1 × 6 mm faces, and therefore parallel to each other, to within a few tenths of a degree. The detectors were then chemically polished and the small ends were ion implanted as described above for the unstressed detectors. Two 250 μm thick sheets of indium placed between the boron-doped faces and two flat copper contact pads extruded when the stress was applied.

Low temperature, low background tests were performed in the helium temperature black-walled box shown schematically in Fig. 1. A small blackbody source and a 150 Hz tuning fork chopper were mounted in one chamber of the cold box. The blackbody was operated at temperatures between 10 and 25 K. Also shown in Fig. 1 are baffles used to trap stray radiation and to define the solid angle of radiation incident on the detector. This arrangement avoided difficulties of attenuator calibration encountered when radiation from an external source is used.

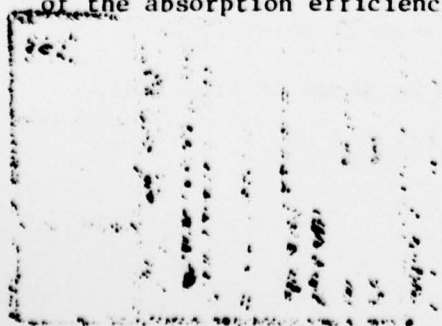
The unstressed detectors were either mounted inside a small shiny brass integrating cavity with a 1 mm diameter entrance aperture as shown in Fig. 2(a),

or directly behind a 1 mm diameter aperture for single pass measurements. The stress apparatus shown in Fig. 2(b) acted as a low Q cavity for the stressed detectors when its front and rear openings were covered with aluminum foil, leaving a 1.4 mm diameter input aperture.

The photocurrent was measured with a conventional transimpedance amplifier circuit⁶ including a cold load resistor and a cold MOSFET operated as a source follower. Negative feedback held the detector bias constant. The output voltage was proportional to the current through the detector. Noise was measured by digitizing the output voltage of the amplifier and using a Fourier transform program on a minicomputer to calculate the noise power spectral density. Relative spectral responsivity was measured in a comparatively high background photon flux by immersing the detector in liquid He at the end of a light pipe connected to a room temperature Fourier transform spectrometer. The spectrometer output was normalized with a Golay cell. In the low background tests the power incident on each detector was calculated by numerical integration of the product of the blackbody spectrum and the relative spectral responsivity of the detector.

The absolute spectral responsivities for a conventional and a stressed detector in their respective integrating cavities are shown in Fig. 3. The performance of three detectors operated at 150 Hz is summarized in Table I. The accuracy of the infrared power calibration is estimated to be $\pm 30\%$.

The quantum efficiency η has been computed by setting the measured values of NEP equal to the photon noise limited results computed from $2h\nu(N/\eta)^{1/2}$. The values of η obtained are large (close to unity) and are consistent with estimates of the absorption efficiency based on the extinction length. We thus conclude that



the measured NEPs are indeed photon noise limited. Comparison of these values of η with the values of the product of quantum efficiency and photoconductive gain $\eta G_{pc} = R h \nu / e$ deduced from the responsivity measurements yields photoconductive gains of 0.32 and 0.29 for the conventional detectors and 0.22 for the stressed detector. The latter number is large considering the length of the stressed detector. This is due in part to the increased hole mobility in stressed germanium.

Experiments at lower flux values indicate that the measured noise is close to the noise limit of our amplifier. Background limited (BLIP) performance at lower values of photon flux would thus require either larger responsivity or lower amplifier noise. The value of current responsivity for the conventional detector in a cavity (24 A/W) is the highest yet reported for a Ge:Ga photoconductor.⁷

It is difficult to compare the performance of different detectors precisely because of differences in amplifier noise, chopping frequency, background level, detector dimensions, and integrating cavities. However the NEPs of our conventional Ge:Ga detectors compare favorably with the best result reported previously in the literature for any modulation frequency and any background level ($4 \times 10^{-17} \text{ W Hz}^{-1/2}$).⁸ They are significantly better than the best reported value at our frequency of 150 Hz for any background level ($9 \times 10^{-17} \text{ W Hz}^{-1/2}$).⁸ The minimum NEP of our stressed Ge:Ga detector is four orders of magnitude better than the best previously reported photoconductive performance for wavelengths beyond 120 μm (NEP = $5 \times 10^{-13} \text{ W Hz}^{-1/2}$ in GaAs).⁹ It is two to three orders of magnitude better than a good bolometer operated at 2 K and 150 Hz.

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TABLE I. Measurement conditions and results for three detectors.

	Conventional		Stressed
	In Cavity	No Cavity	Low Q Cavity
Cutoff wavelength			
at half height (μm)	114	114	193
Peak of spectral			
responsivity (μm)	94	94	150
Operating temp. (K)	3	3	2
Incident photon			
rate N (s^{-1})	4.0×10^7	4.8×10^7	3.4×10^8
Bias field (V/cm)	2.5	2.0	0.42
Peak responsivity R			
at 150 Hz (A/W)	24	7.7	19
ηG_{pc} at 150 Hz	0.32	0.10	0.16
NEP at peak, 150 Hz			
($\text{W Hz}^{-1/2}$)	2.4×10^{-17}	5.0×10^{-17}	5.7×10^{-17}
η	1.2^a	0.34	0.73

^aEqual to unity within the accuracy of our optical flux calibration.

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Figure Captions

Fig. 1 Schematic diagram of low background test apparatus. The low temperature blackbody source and a 150 Hz Bulova^R chopper are mounted in one of the three chambers in a He temperature Cu box with black absorbing surfaces. A conventional detector in an integrating cavity is shown in the test position. A Hughes W164 MOSFET and a $3 \times 10^{10} \Omega$ Eltec feedback resistor were used in the cooled portion of the amplifier.

Fig. 2 (a) A conventional detector supported on a steel post inside an integrating cavity formed in a brass block with a 3.7 mm drill. (b) A detector mounted in the assembly used to produce uniaxial stress. The stress is applied with a 1/4-80 screw through a ball bearing, a snugly fitting piston, paper insulators, and Cu and In pads.

Fig. 3 Measured spectral responsivity of a conventional and a stressed detector, when enclosed in the integrating cavities described in the text. Other properties of these detectors appear in columns 1 and 3 of Table I.

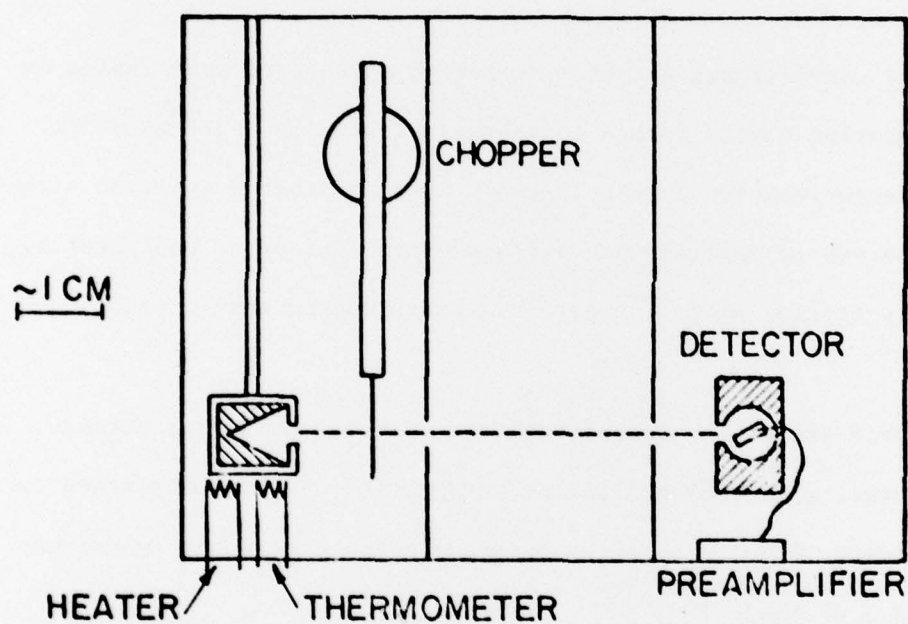


Fig. 1 (XBL 7812-13634)

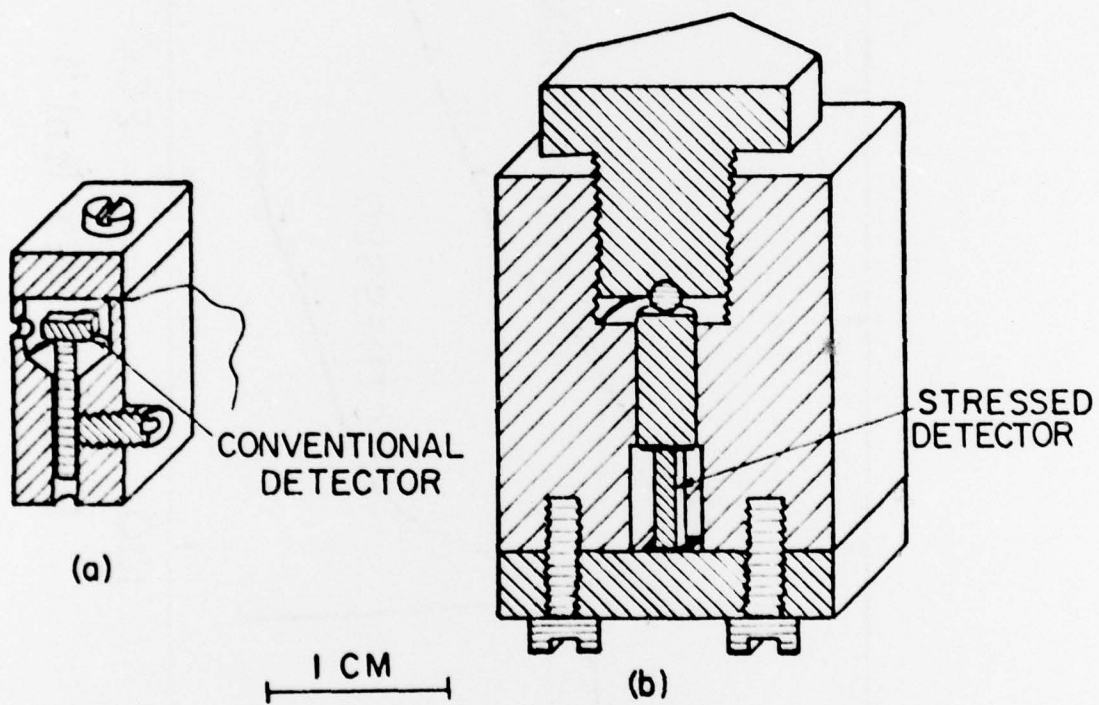


Fig. 2

XBL 7811-6152

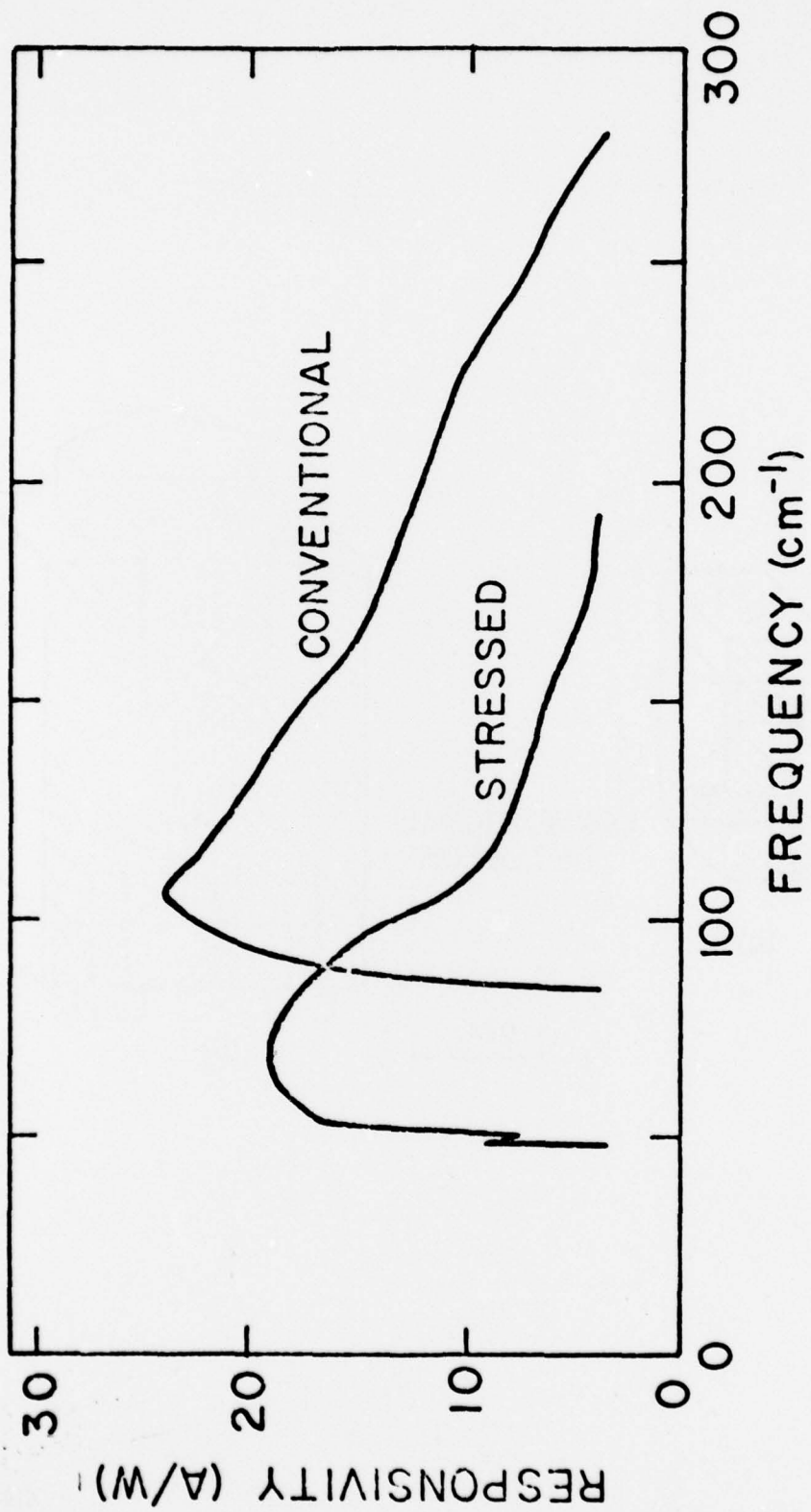


Fig. 3

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