N90-21320

The Potential for High Performance HgCdTe Arrays at 4 Microns

G. H. Rieke, M. A. Sarfaraz, M. J. Rieke, and E. T. Young
Steward Observatory, University of Arizona

I. Introduction

The 3 to 4.5 micron spectral interval is of great interest for astronomy. In this interval, there is a minimum in background from earth orbit between the spectrum of solar light reflected by zodiacal dust grains (which dominates toward shorter wavelengths) and the thermal emission of these same grains (which dominates toward longer wavelengths). Coincidentally, the emission of stars in the galaxies as they first formed is likely to be redshifted into this wavelength interval. As a result, observations of great depth can be made with space borne infrared telescopes such as SIRTF that could extend to realms in the early Universe that are presently unobservable and that would provide entirely new insights on the formation of our galaxy and its environment.

There is also substantial interest in infrared spectroscopy over the same interval. Shortward of 1 micron, atomic lines dominate the spectra of astronomical sources; increasingly with longer wavelength, however, molecules become observable. Molecules exist in dense, cool regions of space where, for example, star and planet formation occur. Particularly for groundbased instrumentation, the thermal background emission of the telescope and atmosphere rises steeply toward 10 microns and atmospheric opacity increases dramatically longward of 15 microns, making sensitive molecular detections very difficult beyond 5 microns. Thus, the 3 to 4.5 micron region is very significant in understanding the origins of the solar system and of stars and planets.

Both of these applications are in part of interest because of the low backgrounds that make high sensitivity observations possible. To exploit these possibilities requires detectors and readouts of very high sensitivity. In the following, we have evaluated the potential of existing technology at Rockwell International in terms of the goals for astronomical detector arrays in the 3 to 5 micron interval.

II. Measurement Technique

A test system was built to allow operation of individual detectors over a temperature range of 5 K to 100 K. An integrating JFET amplifier allowed measurement of the current through the diode with an accuracy of a few electrons/sec or better. The diodes viewed a a variable infrared source through a fixed filter at 3.4 microns to measure the relative response.

The tests were conducted in a liquid helium dewar. The detector chip carrier is mounted in a connector on an aluminum block that is mounted to the work surface of the dewar through four fiberglass stalks that provide thermal isolation. A gold-plated copper bar screws to the aluminum block and presses the chip carrier into the connector, providing a large surface area for uniform cooling of the chip carrier; a hole in the bar allows introduction of infrared radiation to the test sample. This copper bar is attached by a gold-plated copper foil to a heat switch that allows sinking the copper to the helium work surface or disconnecting this thermal path through an external actuator. A thermometer on the bottom of the aluminum block monitors the temperature; a heater is also provided in this location. Over the top of the copper bar and chip carrier there is a baffle that carries the infrared filter, which for all these tests had a bandpass of 0.1 microns centered at 3.4 microns. A second baffle box encloses the entire thermal stage and carries a filament from a small light bulb as a source of infrared radiation.

The JFET integrating amplifier was supplied by Infrared Laboratories, Inc. The amplifier is mounted on a header using insulating rods of polyamide and is provided with a heater. The header is cold sunk to the liquid helium work surface of the dewar and the heater current was adjusted to bring the amplifier to its optimum operating temperature. The output of the amplifier passes through a number of stages of gain and a low pass filter, and is then digitized and fed into a Compaq computer. The computer controlls the data-taking cycle by resetting the amplifier and collecting data as charge accumulates on the gate of the amplifier. The resulting voltage ramp is fitted with a straight line to estimate the current flowing onto the gate. The system was calibrated by measurement of the various gains and of the input capacitance of the amplifier (5 pf). A nominal allowance of 1 pf was made for the additional capacitance of the detector and wiring; because of the large capacitance of the amplifier, small variations in the detector capacitances will have little effect on the currents deduced. Errors in the current measurement are estimated from the repeatability of a series of measurements, each of which is 10 to 15 seconds in length. In cases where large currents were to be measured, the computer is replaced with a storage oscilloscope and the voltage slopes are estimated from the oscilloscope display.

An important aspect of the apparatus is that only the temperature of the detector (and infrared filter) were varied during the measurements, not the infrared stimulator or the output amplifier. As a result, any temperature-dependent changes could be attributed confidently to the detector.

Measurements were also made on the temperature dependence of the operation of a Rockwell-supplied NICMOS 2 switched FET readout. These tests were conducted with a dewar and control system designed and constructed by R. Rasche, G. Winters, and R. Schnurr of the NICMOS project. The NICMOS 2 MUX (without detector material) was attached to a copper block mounted on the work surface of the dewar. A thermometer and heater were embedded in the same copper block. The dewar work surface was cooled with liquid helium to ~ 10 K, and then allowed to warm up; the temperature of the detector mounting block increased roughly at the rate of 0.3 K/min, so measurements were always in a state of pseudo-equilibrium.

III. Results

Measurements have been obtained for a number of samples of HgCdTe diodes manufactured by Rockwell International. All the diodes reported on here had cutoff wavelengths at high temperatures of 4.6 to 4.7 microns. Although no confirming measurements were made, the cutoff wavelength is expected to move to 5 microns or beyond at the low temperatures of our tests. Diode sizes ranged from 20 to 150 microns. The test program yielded full diode curves and relative response at 3.4 microns for the sample diodes as a function of temperature. Dark currents are quoted below as the current passing through the diode with a back bias of 50 mV.

The various diode types showed a wide range of behavior, both with regard to dark current and responsivity. The test results for one of the best diode types are illustrated in more detail in Figure 1. This detector has a size of 148 microns and a cutoff wavelength of 4.61 microns.

The behavior in Figure 1 is fairly typical of the other good diodes. For all of these detectors, responsivity fell with decreasing temperature with most of the change occurring between 45 and 25 K. Little further change was observed below 25 K. At low temperatures, the responsivity was 40 to 50% of that observed at 60 to 70 K. Assuming the quantum efficiency at these higher temperatures is ~ 60% (K. Vural, private communication), the diodes operated with quantum efficiencies of 25 to 30% even at the lowest temperatures encountered in these tests (~ 5 K). The dark currents fell rapidly with decreasing temperature to 30 to 35 K. Below this temperature, the currents were constant, at values as low as 30 to 60 electrons/second.

The NICMOS 2 MUX functioned correctly above 36 K. Below 36 K, a shift register on the output failed and only two rows of the array could be read out. The MUX resumed full operation between 21 and 24 K, below which it was again inoperative. Under the assumption that the input capacitance is 0.05 pf (the value measured at 77 K) at all temperatures, the read noise is as in Table 1. The entries at 37 and 24 K should be interpreted as upper limits, since the results may be affected by the lack of complete temperature stability. In addition, the optimization of the voltage levels and other operating parameters had not been completed at 77 K, and no attempt was made to re-optimize for the lower temperatures. It is possible that further adjustment of operating parameters would both improve the read noise and extend the temperature regions of operability.

IV. Conclusion

Although none of the components we have tested was developed for the low temperature operation required for ultimate faint signal performance at 4 microns, it appears that judicious selection of diode type and MUX operating conditions would produce an array at or beyond the current state of the art. It is to be hoped that further improvements could be achieved by further development, for example by using a multiplexer design that would operate solidly below 30 K and perhaps by modifications in the diode architecture to enhance the response and reduce dark current at very low temperatures.

Acknowledgements

We appreciate the contributions of R. Rasche, R. Schnurr, and G. Winters to our measurements of the NICMOS 2 MUX. K. Vural provided helpful advice regarding these tests. This work was supported by NASA and is part of the technology development for the Multiband Imaging Photometer for SIRTF.

Table 1. Read Noise for NICMOS 2 MUX

T (^{o}K)	Noise (electrons rms)
77	42
37	$\leq$ 78
24	$\leq$ 92

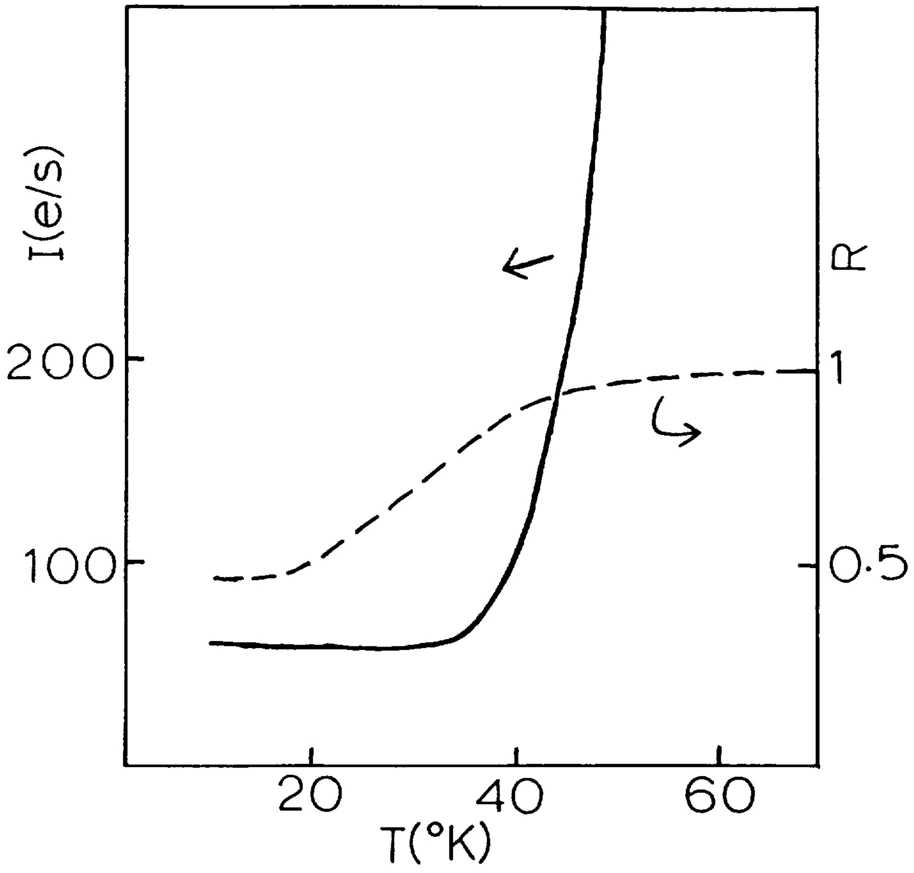

Figure 1. Dark Current and Relative Response for a HgCdTe Diode. Response is measured at 3.4 microns and is referred to 1.00 at 70 K, as indicated on the right scale. Dark current is measured under 50 mV back bias and is given in electrons/sec on the left scale. The diode is 148 microns in size and has a nominal response cutoff at 4.61 microns.