Total Dose Testing of a CMOS Charged Particle Spectrometer

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INTRODUCTION

CMOS Charged Particle Spectrometer chips [1], designated CPS32, have been developed for an experiment on the STRV-2 spacecraft. These chips, which are a form of Active Pixel Sensor (AI%), were designed for proton and electron energy spectrometry. During the 1 year mission they will be exposed to an estimated dose of 10 krad (Si), and will operate at unregulated ambient temperatures expected to vary from -40°C to +60°C. This paper presents the results of total dose testing on these chips, which were fabricated in a standard commercial process.

CPS32 DESIGN

The CPS32 consists of a 32x 32 array of multiplexed pixels. As shown in Figure 1, each pixel contains a photodiode sensing element, along with multiplexing and readout circuitry. Also included on the CPS32 are pFET dosimeters [2] and multiplexer channels for the dosimeters and an external temperature sensor. The chips were fabricated through the MOSIS service in the Hewlett-Packard 1.2μ n-well process.

The design of the CPS32 is essentially identical to a standard source-follower-per-detector (SFD) infrared multiplexer [3], except that in this case the photodiodes are integrated monolithically on the silicon. A more significant difference, from a radiation perspective, is that the CPS32 will not be operated at cryogenic temperatures. The design differs from other APS designs [4] in that the CPS32 does not have sample-and-hold circuitry or separate signal and reset signal paths. This was done to avoid possible problems due to proton events in the storage circuits. The CPS32 also has no control logic beyond address decoding.

There are two other features unique to the CPS32. First, the pixel was designed entirely within the n-well, with p-channel transistors and a p+/n diode. This was expected to reduce the radiation induced dark current and the subthreshold leakage in the reset transistor. As a result, the collection volume is limited to about half the well thickness, producing a dE/ dx detector. Second, to avoid possible peripheral leakage, the reset transistor was made edgeless, completely surrounding the photodiode.

SPECTROMETER PERFORMANCE

For charged particle spectrometry, the CPS32 is operated in the correlated double sampling mode [3], with a reference frame subtracted to remove fixed pattern offset and dark current. The residual is then histogrammed. The conversion gain was determined by the mean-variance method to be 2.4 μV/e$^-$, with a read noise floor of -55 e-. Figure 2 shows a histogram of an Am^{241} source, which produces 60 keV X-rays (the shoulder on the dark peak) and 5.4 MeV alpha particles (the small peak at 150 mV). We believe that the width of the alpha peak is primarily due to the energy spread of the source, and are planning proton tests in an accelerator to determine the true resolution. This measurement indicates a sensitivity of 270 μV/(MeV cm^2/g). With a noise floor of 130 μV, this gives a resolution of 0.5 MeV cm^2/g.

TOTAL DOSE TESTS

Total dose tests were performed using the JPL Co^{60} source, at a dose rate of 10 rad(Si)/s. Irradiations were performed at room temperature with full bias and clocking. Measurements were taken immediately after irradiation, although measurements taken at later times showed no changes.

After irradiation, the parts were characterized, and threshold voltage shifts were measured. ΔVt_p was -2.6 mV/krad, as measured by the pFET dosimeter, consistent with previous JPL experience. ΔVt_n was -1.3 mV/krad, from the characteristics of the output source follower nFET. As expected from these small shifts, there was little effect on operating voltages, dynamic range or conversion gain.

The primary effect, as anticipated, was a dramatic increase in the dark current. As shown in Figure 3, the increase is linear with dose. Dark current was measured temperatures of -25°C, 0°C, and +25°C, with integration times of .1 to 10 seconds. An activation energy $E_a = 0.49$ eV was measured, as shown in Figure 4, demonstrating that, as usual, dark current performance can be recovered by cooling. The radiation induced dark current, when scaled for the conversion gain and pixel area, is 0.2 nA/cm^2 krad at room temperature. It is believed, however, that the radiation induced dark current originates along the periphery of the diode.

Figure 5 shows the distribution of the radiation induced dark current. The spread, of 7%, is considerably less than the original 40% spread of the pre-irradiation dark current. The distribution is Gaussian, and the only outlier has a deviation of just 6σ.

The noise floor, measured for short integration times, showed no measurable change with dose or temperature. In situations where there was a significant dark signal, however, the noise level was much higher than would be predicted by shot noise. This excess noise associated with dark current was also seen for long integration times before irradiation. It increases rapidly with the dark signal level, as shown in Figure 6, and seems to depend only on the magnitude of the dark signal. The excess noise is very important to device operation. In order to achieve the desired signal-to-noise ratio, the operating temperature must be lower (or the integration time shorter) than would be required for dark current with shot noise only. The source of the excess noise is unknown, but is currently under investigation.

REFERENCES

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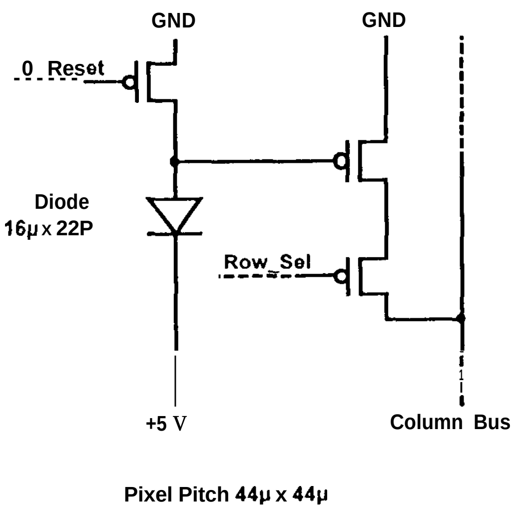


Fig. 1. The CPS32 pixel design.

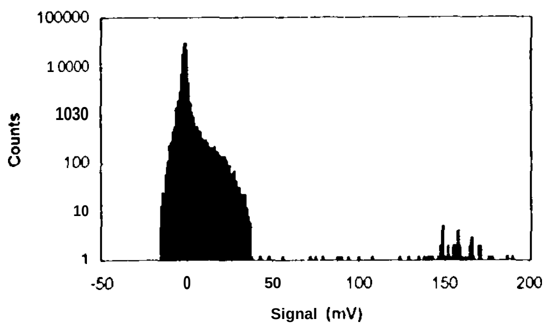


Fig. 2. Am^{241} spectrum taken from 100 frames of 0.1 seconds each.

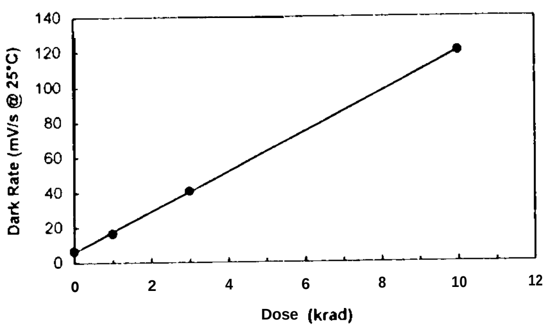


Fig. 3 Dark current *vs.* dose at room temperature.

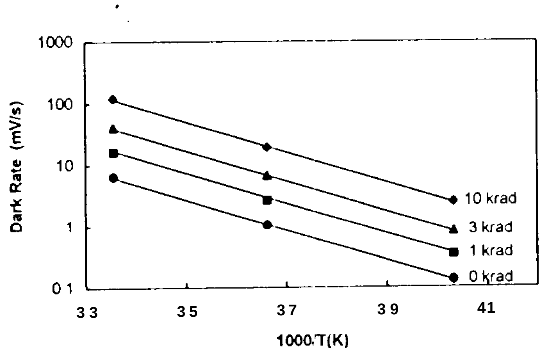


Fig. 4. Dark current *vs.* temperature.

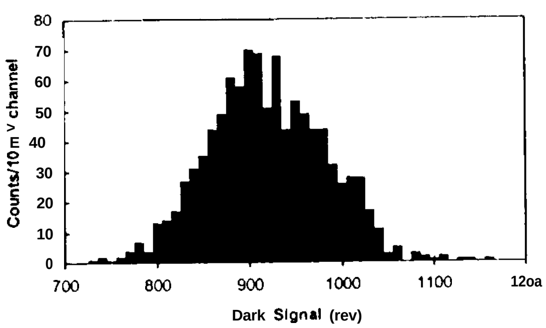
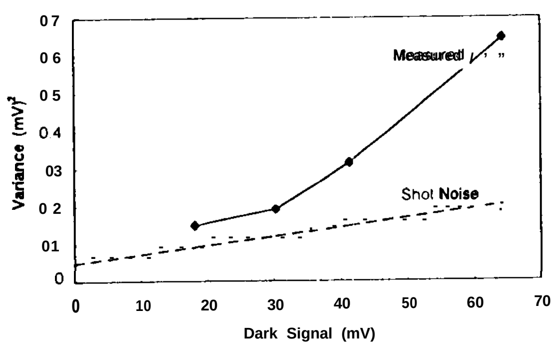


Fig. 5. Dark current distribution at room temperature after 10 krad.



F ig. 6. Signal variance *vs.* signal mean at room temperature after 10 krad.