Simplified Readout of UVPROM Dosimeters for Spacecraft Applications

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***Abstract*—A simplified procedure for measuring the absorbed dose using floating-gate transistors is presented and demonstrated on 64 K UVPROMs. Reading the dosimeter involves a standard electrical readout at 5 V, generates shifts in the response curve that are proportional to absorbed dose, and is suitable for applications on spacecraft.**

***Index Terms*—Dosimetry, FGMOS devices, radiation effects, total ionizing dose.**

I. Introduction

PREVIOUS studies have shown that floating gate transistor cells (See Fig. 1) can be used as radiation dosimeters [1]–[3]. Exposure to ionizing radiation reduces the amount of UV exposure needed to erase (induce a change from the "0" to the "1" state) the individual memory cells. In ground-based applications, this reduction in required UV exposure can be measured directly by direct measurement of the remaining UV exposure needed to erase all the cells. The amount of charge removed from each gate is assumed proportional to the reduction in the total UV (before and after exposure to ionizing radiation). In space applications, electrical readout is required because UV exposures are impractical. This requires a digital readout method for measuring the amount of charge removed.

The solution for the MPTB satellite experiment was to partition the memory array into blocks of 8000 memory cells in which all the memory cells in each block were programmed to the "0" state with a specific amount of charge. The amount of charge on the floating gates in each block decreased linearly with the block number. The entire memory array was then read starting with 5 V on the control gate and continuing through voltages ramping up to close to the programming voltage [4]. This method requires considerable telemetry or on-board processing, and the data (shifts in the response curves) are complicated to translate into estimates of absorbed dose. However, the method has been demonstrated on the MPTB satellite, and is still providing reliable data [5].

In this paper, we present a simpler readout procedure than that used on MPTB, one that requires only a single readout at 5 V instead of a series of reads as a function of the voltage on the control gate. This eliminates the need to ramp the control gate voltage, greatly reduces the time required for measurements as well as the amount of telemetry or on-board processing required for accurate dose measurements. Most important, the data converts easily and directly into estimates of the absorbed dose. Instead of a response curve that changes with absorbed dose in a complicated manner, we obtain a simple shift whose magnitude is proportional to the absorbed dose.

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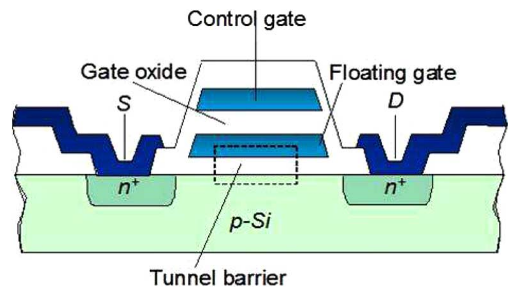

Fig. 1. Floating gate transistor cell of the type used in UVPROMs. Negative charge is stored on the floating gate to define the transistor in the "0" or off state. Removal of the charge by exposure to UV radiation or ionizing radiation reduces the amount of charge on the gate. The amount of the reduction obtained by exposure to ionizing radiation can be measured directly by a follow-up exposure to UV measuring the duration required to complete the erasure. The reduction in required UV exposure is proportional to the absorbed dose [1]–[3].

II. Method

Fig. 2 shows a schematic of the system used during readout of the UVPROM memory array in this experiment, and Fig. 3 shows physical setup used in this study. The results of successive reads of the memory as a function of the ramp voltage are plotted as number of "0" to "1" transitions (bit flips) versus control-gate voltage in Fig. 4. The different curves in the figure represent the measurements obtained following different durations of UV exposure. These UV exposures were meant to simulate the effects of different levels of ionizing radiation. When obtained in this manner, the major shift with duration of exposure is the number of bit flips at low voltage, and this number is relatively independent of the voltage on the control gate. In what follows, therefore, all readings of the memory are performed with 5 V on the control gate. Note that there are no cells in the "1" state until over 200 s duration of UV exposure. Similarly, no cells would flip to the "1" state following low levels of exposure to ionizing radiation. To make the UVPROM a valid dosimeter, it has to be made sensitive to even low levels of ionizing radiation. This is accomplished by partitioning the memory array as explained below.

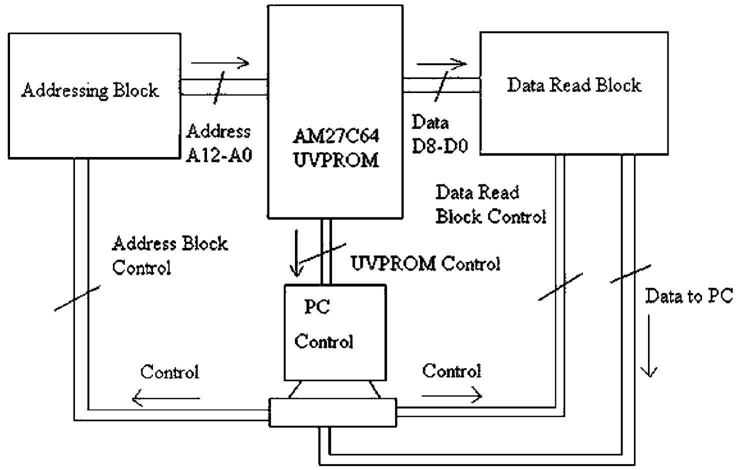

Fig. 2. Schematic of the readout circuit for the AM27C64 UVPROMs. These devices have flown on the MPTB satellite and are being incorporated into the DIME experiment package for possible flight as part of NASA's SET program.

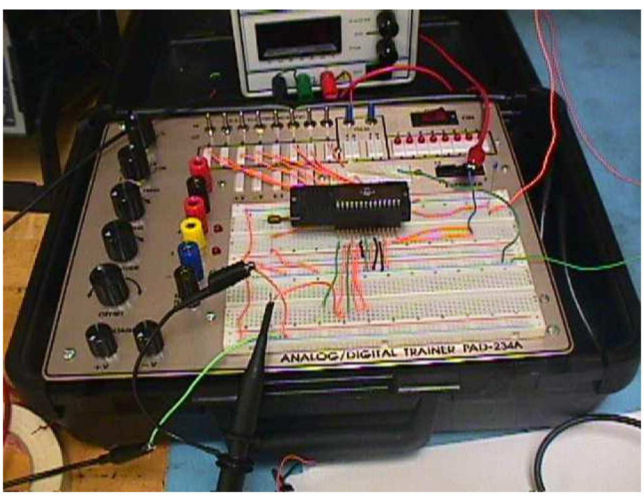

Fig. 3. Physical layout used for readouts of the AM27C64 UVPROMs.

A. Preparation of Memory Blocks

The memory array was divided into 16 blocks where all memory cells in each block have the same amount of charge on the floating gate, and the amount of charge on each gate in a block decreases with the block number. The 16 different levels of charge on the floating gate were established as follows: all memory cells were fully programmed by saturating the floating gates with charge. Then all cells were exposed to UV for a duration equivalent to 1/16 that needed to erase the entire array. Then partitions 1 through 15 were fully reprogrammed. All 16 partitions received a second dose of UV and partitions 1 through 14 were reprogrammed. This sequence was continued until only partition 1 was fully programmed and partition 16 had been completely erased. Following partitioning, the memory was read with 5 V on the control gate and the number of "1" states in each partition was counted and plotted against how much UV exposure the partition received, as shown in Fig. 5.

III. Results

The effect of exposure to ionizing radiation is to cause more cells in the upper partitions and some in the lower partitions to flip with the effect of causing the response curve to shift to the left. This is illustrated in Fig. 6 for an exposure of 33 krads. Fig. 7 plots the shift measured on response curve at the level of 50% bit flips versus the absorbed dose. The shift in the response curve is proportional to the absorbed dose even when each data point is obtained with a different device.

An alternative method for determining the absorbed dose is to measure directly the reduction in the duration of UV exposure needed to complete the erasure of the device. This is the method used in our ground-based measurements to date, and it has the advantage of being an analog measurement. The question is how much sensitivity is lost by switching from optical (UV erasure) to electronic readout of the devices? This question is addressed in Fig. 8 where the shift in the response curve is plotted versus absorbed dose both for devices read out using the optical method and for identical devices read out with the electronic method. The optical (analog) technique is clearly more sensitive to increases in absorbed dose. However, the optical readout is destructive in that the data is erased while the electronic readout preserves the data for future reference. In many dosimetry applications, this data retention is worth the small loss in sensitivity. Moreover, electronic readout can be used more easily on spacecraft or other remote sensing applications since the readout procedure is identical to reading any UVPROM. It is small, rugged, requires no power during the exposure, and it is simple to implement in any circuit.

It is important to note that since the UVPROMs are not turned on during exposure, the peripheral circuits are not significantly effected by the absorbed dose and are capable of reading the dose over the entire range of sensitivity.

A. Annealing

Measurements were repeated after intervals of 1 month and 12, months. Control devices exhibited average shifts of 41 fewer cells in the "1" state than before irradiation. Following 1 month, the controls exhibited 458 fewer, and 3911 fewer

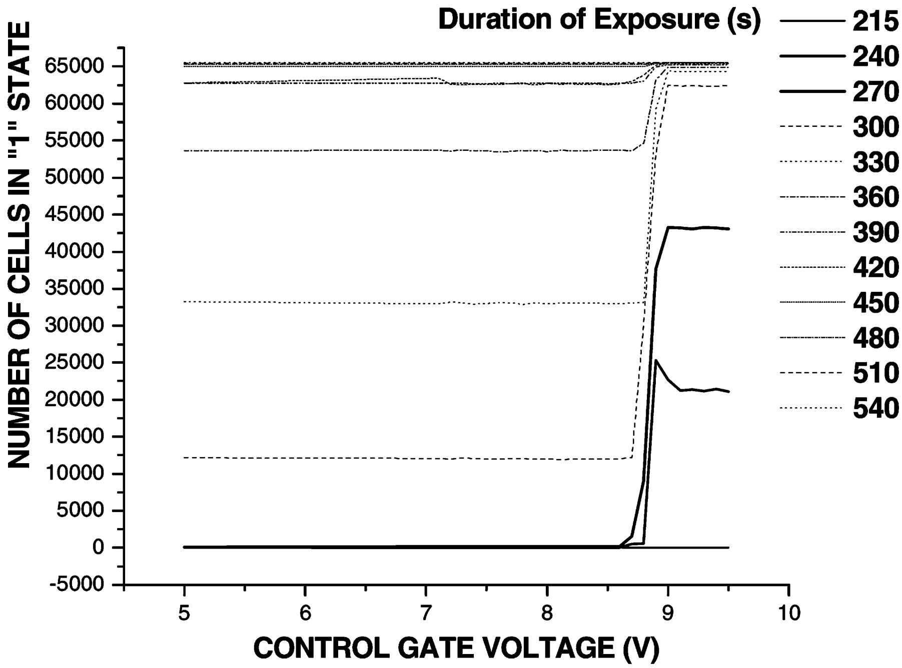

Fig. 4. Integral number of bit flips (transitions from "0" state to "1" state) plotted versus the voltage on the control gate of each floating gate memory cell during readout. Curves are following different durations of UV exposure given in seconds. The effects of exposure to different levels of ionizing radiation would be similar. UV exposures shorter than 215 s are indistinguishable from the 215 s curve.

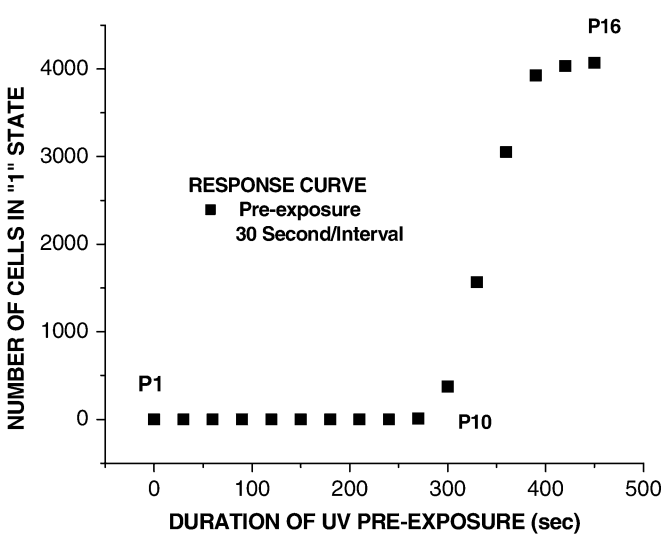

Fig. 5. Response curve: Plot of the number of cells in the "1" state for each memory block plotted versus the duration of UV exposure the cells in the block received during preparation. This curve is typical of the response curve before the device is exposed to ionizing radiation. The floating gates of the memory cells in partition 16 have almost no charge while those in block 1 are fully charged. Each successive partition above partition 1 has had its charge reduced by 1/16 of the original compared to the proceeding partition. After 300 seconds of UV exposure, some cells are in the "1" state even before exposure to ionizing radiation.

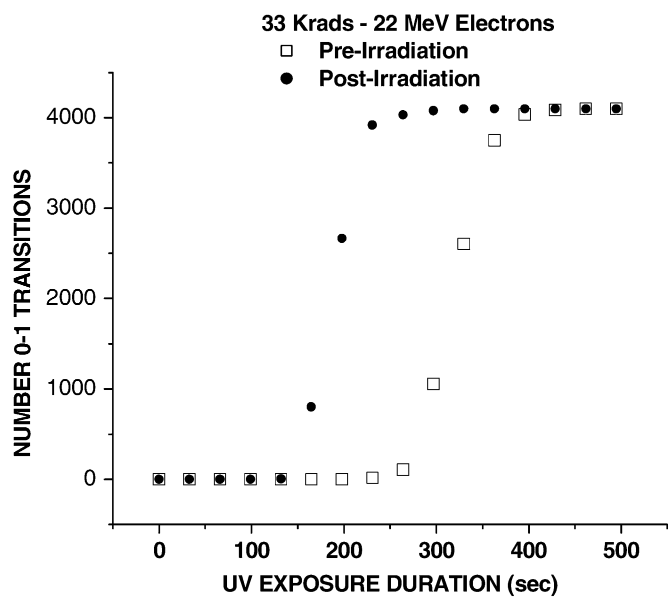

Fig. 6. Comparison of response curves before and after an exposure to 33 krads of 22 MeV electrons for a device partitioned into 16 blocks of different sensitivity. Memory blocks that had many cells in the "1" state before the exposure become saturated and other partitions begin to show evidence of cells in the "1" state giving the appearance of the response curve shifting to the left. The location of each partition data point along the abscissa is completely determined by the UV exposure received during preparation of the device. The apparent shift in the curve increases with absorbed dose.

after 12 months. The data for each interval were renormalized by adding the average shift in the controls to each data point. The results for both intervals are compared with those following immediately after exposure in Fig. 9. The results show no evidence of an effect of annealing on the shift in the response curve as long as the data is corrected for the shift in the non-irradiated parts.

IV. CONCLUSION

A procedure for reading UVPROM dosimeters has been developed that allows for electronic readout of the UVPROMs, and only requires a single readout of the logic state of each memory cell in the array. This reduces greatly the time and telemetry required for processing a measurement of absorbed

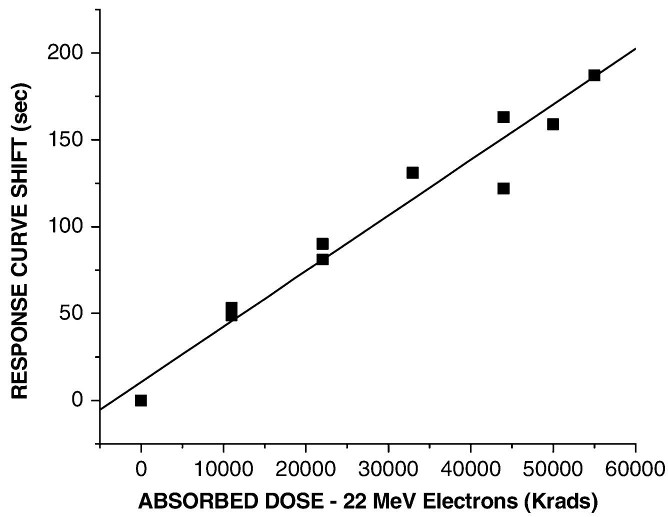

Fig. 7. Shift in the response curve versus absorbed dose for an exposure to 22 MeV electrons. Each data point was obtained with a separate AM27C64 UVPROM device.

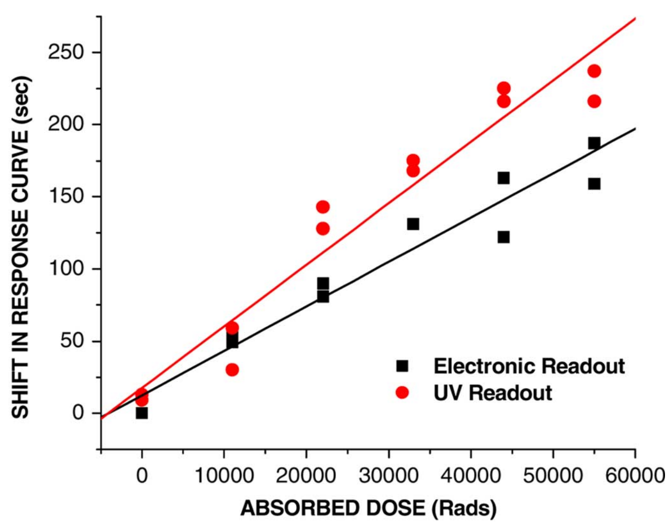

Fig. 8. Comparison of the shift in response curves with absorbed dose for electronic and optical readouts. Both are proportional to the absorbed dose, but the optical readout shows somewhat higher sensitivity for the optical readout. (5 sec/Krad versus 3 sec/Krad).

dose compared to a similar system using the same AM27C64 UVPROMs that we are flying on the MPTB satellite experiment. The shift in the response curves obtained with the new electronic readout method and the optical readouts are both proportional to the absorbed dose over the range of doses measured. This is a significant improvement over the earlier electronic readout on MPTB which had a non-linear dependence on dose. While the electronic readout is somewhat less sensitive, it has great advantages for convenience, automation, and remote applications such as spacecraft and radiation therapy. This new single-read procedure will be the method used in the DIME experiment scheduled to fly on NASA's upcoming SET-1 mission.

The sensitivity of the floating gate technology using this readout procedure also allowed us to increase the number of blocks from 8 blocks on MPTB to 16 in this study. We have successfully used as many as 32 blocks on the 64 K UVPROMs used in this study. We have successfully implemented up to

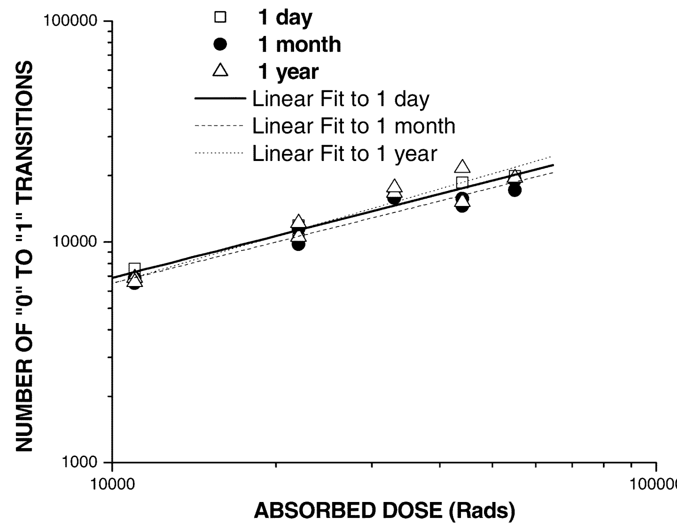

Fig. 9. Shift in the response curve versus absorbed dose for measurements on the same devices carried out 0, 1, and 12 months following exposure to 22 MeV electrons.

128 blocks on 8 Mbit devices [9], and we are planning to use 16 blocks for the 64 Kbit devices and 32 blocks in the 8 Mbit devices to be included in the DIME experiment on SET 1. Clearly, the number of blocks used increases the resolution with which the position of the Response Curve can be determined, and therefore, the accuracy with which the shift (and therefore the dose) can be read. The number of blocks into which a memory array can be divided is only limited by the number of cells in the array. For this reason, the Podova University and Clemson groups have proposed using the 8 Mbit arrays from ST Microelectronics and this procedure for dosimetry trials also as part of the DIME experiment and as part of a longer-range study to determine the potential sensitivity for these devices.

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