DIME -1: The Passive Components of the Dosimetry Intercomparison and Miniaturization Experiment

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ABSTRACT

DIME consists of six dosimeter systems placed on two 3U boards. This paper describes the passive component, DIME-1 which monitors TID using RadFETs and UVPROMs as well as SEE versus critical charge in UVPROMs.

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INTRODUCTION

Spacecraft systems are subject to a variety of different radiation environments. Risk of a given effect depends on orbit and the shielding surrounding the vulnerable system, and the solar activity at the time. Moreover, these radiations can generate a variety of problems due to gradual deterioration due to total ionizing dose (TID) or catastrophic single-event effects (SEE). The latter are typically independent of previous exposure, and they are as likely to induce effects near the beginning of the mission as at the end. SEE are typically generated by traversals of an SEE-sensitive volume by particles that have a high effective LET (linear energy transfer) or by those that deposit a similarly large amount of localized energy through nuclear spallation reactions. If and when important systems malfunction, it is important that spacecraft operators quickly determine whether one of these radiation effects has been sufficiently intense to be a plausible cause of the problem.

The equipment necessary to characterize in detail the particles and their energies that comprise the radiation environment at a given location within a spacecraft would be too bulky and require too much power to fly on any but dedicated research satellites. Moreover, the data collecting and analysis from such elaborate measurements would not be completed in time for emergency situations. Simple dosimeters that provide measurements of total ionizing dose (TID) without some effort at energy discrimination or some measurement related to the SEE potential of the storm will not provide sufficient information for spacecraft operators to characterize system failures, SEE, or even increases in sensor noise, especially at locations that have different levels of shielding.

In this paper and its companion paper on DIME-2, we describe a set of simple dosimeter systems that are designed to characterize the environment in terms of the specific radiation effects of concern, in particular: TID, SEE, and displacement damage and to provide data that can be easily interpreted by the spacecraft operator. DIME consists of six dosimeter systems placed on two 3U boards, each board with its own processing capability. It is designed to monitor the varied radiation environments of space in terms of the radiation effects of principal interest: Total Ionizing Dose, Displacement Damage, and Single-Event Effects. The first board, DIME-1, which is the subject of this paper consist of nine dosimeters, six RadFETs under different thicknesses of aluminum and tantalum hemispherical shields, and three FGMOS dosimeter arrays. This board does not require power during exposure, and it must only be turned on to read the accumulated absorbed dose. In the second mode, the board is only powered up to read the accumulated absorbed dose. If, instead, power is continually applied, it will provide increased sensitivity to incident ionizing radiation. The RadFETs provide data on TID under different levels of aluminum and tantalum shielding (1). The UVPROMs programmed as dosimeters (2-5) provide TID measurements over a wide range of exposure levels as well as single-event upset measurements as a function of threshold for upset (critical charge) in three non-volatile memories. DIME-2 provides effective LET spectra from two arrays of p-i-n volumes. It also provides sensitive measurement of TID through an instrument that measures optically stimulated luminescence generated as a result of exposure to radiation. DIME 2 is described in a companion paper. Both DIME flight boards have been delivered to NASA for the SET-1 mission of the Living With a Star program. It is scheduled to fly as part of the Air Force's DSX satellite in about the year 2010

DETAILS OF DIME-1

The flight board for DIME-1 is shown in Fig. 1. It is designed to fly in a power-off state while acquiring data. The TID effects being monitored are cumulative, and all reads are non-destructive. The board contains six RadFETs aligned along the bottom of the board. During flight, they would sit under hemispherical shields of different thickness of shielding material, three aluminum and three tantalum.

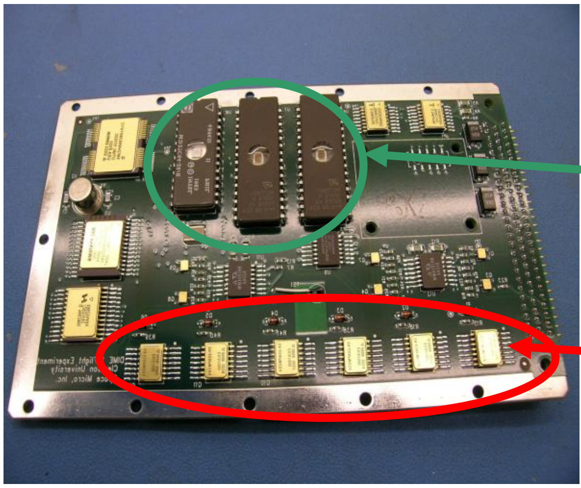

Fig 1. *DIME 1 is shown with six RadFETS along the bottom of the board and three UVPROM dosimeters. The board has a mass of 0.2 kg and requires < 0.5 W to read the sensors.*

TID Measurements with RadFETs

RadFETs are a standard form of dosimeter, and space workers have considerable experience with them. I refer the interested reader to the Tyndall website (2) for more detailed information about the type of PMOS dosimeters used here as well as some calibration data. More extensive calibrations for both protons and electrons are being carried out by Ken LaBel and colleagues at NASA GSFC.

TID Measurements in FGMOS Arrays

The floating gate transistors are distributed in the standard pattern for UVPROM memories. In fact, commercial memories were programmed as dosimeters for flight parts on DIME-1. Programming consists of dividing the memory array into 32 regions or blocks. All memory cells in a given block are programmed with the same amount of charge being placed on the cell's floating gate. The amount of charge increases linearly with the block number starting with the least charge on cells in Block 1 and the most charge stored on gates in the cells of Block 32. All cells in Block 1 should be in the "1" state while all cells in Block 32 should be firmly in the "0" state. Somewhere in between, there is a transition region where the blocks have contributions of both cells in the "0" state and cells in the "1" state. The UVPROMs are read as they normally would when the UVPROMs are programmed as memories (fully charged for the "0" state and no charge for the "1" state.

The active transition region consists of those blocks where the cells are distributed between the two states . This is illustrated in Fig. 2 where the number of cells in the "1" state are plotted versus the block number that the cells are in. Plots are given for absorbed doses of 10, 110, and 910 rads. The cells in the transition region change states even when exposed to relatively small amounts of radiation (<< 1 rad) but more than 1 Mrad is needed to flip all the cells in the array. The response curves shown in Fig. 2 shifts to the right following exposure to ionizing radiation, but as can be seen, the shift is extremely small even for doses as high as 1 Krad. The integral under the curve, which is just the number of cells in the "1" state, is a more sensitive monitor of absorbed dose. Better still is the number of "0 to 1" transitions induced as a result of exposure to TID, as illustrated in Fig. 3 for the same data set. This data is consistent with earlier data obtained with a different measuring system. This earlier data set shown in Fig. 4 covers a range of absorbed dose that covers the range expected in the SET-1 mission.

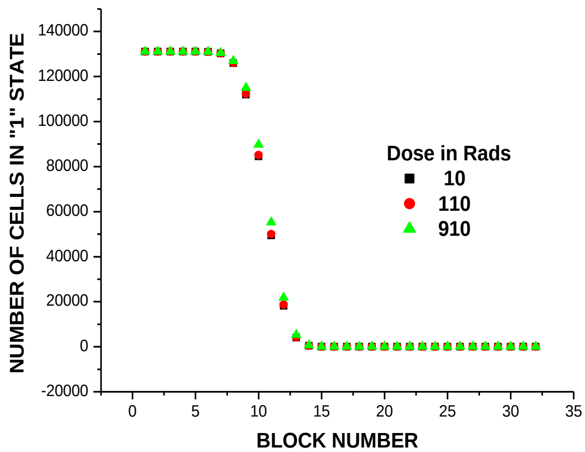

Fig. 2 Response curve for a UVPROM programmed as a dosimeter. The active region is the transition region of memory blocks that contain some cells in the "0" state and some in the "1" state. The transition region shifts gradually to the right. Shifts from doses below 1 Krad are clearly difficult to distinguish

Potential Improvements

The range of exposures covered in Fig. 4 is sufficient for most spacecraft applications, but further improvements in sensitivity and accuracy are being developed. One approach is to control temperature and voltage fluctuations, or at least correct for them, especially while reading the dosimeter. Another simple approach being explored is to apply V_{CC} to the device during exposure and to expand the active transition range so that it covers the entire memory array. Preliminary data suggest that this combination results in over two orders of magnitude increase in sensitivity as illustrated in Fig. 5.

SEU Measurements in FGMOS Arrays

Cells in blocks to the right of the transition region have different amounts of charge on their floating gates (proportional to the block number), and as a result, have different thresholds for upset. Monitoring the number of isolated cell flips beyond the transition region provides counts of SEU event as a function of threshold or critical charge (2). In the analysis, one must record when an event occurred since the critical charge is changing with block number due to the high levels of absorbed dose.

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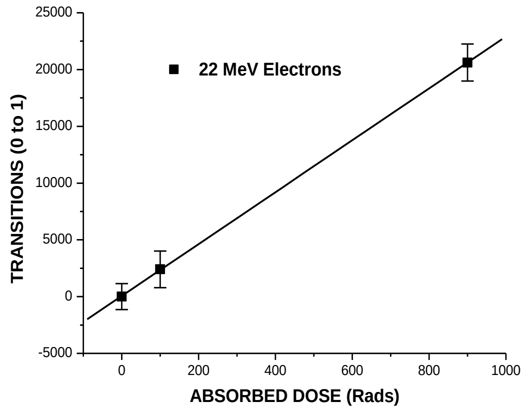

Fig. 3 The number of cells in the "1" state plotted versus the TID exposure measured in rads. The shift as a result of the same three exposures illustrated in Fig. 2.

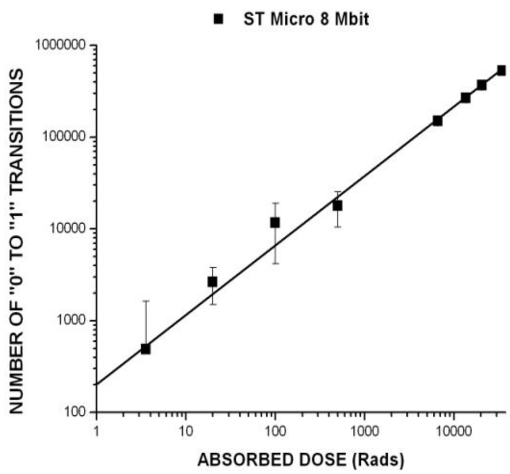

Fig. 4. The increase in the number of cells in the "1" state plotted versus the absorbed dose. The solid curve is a linear best-fit to the data. The y-intercept suggest that programmed and read this way, it takes about 0.005 rads to flip the average cell.

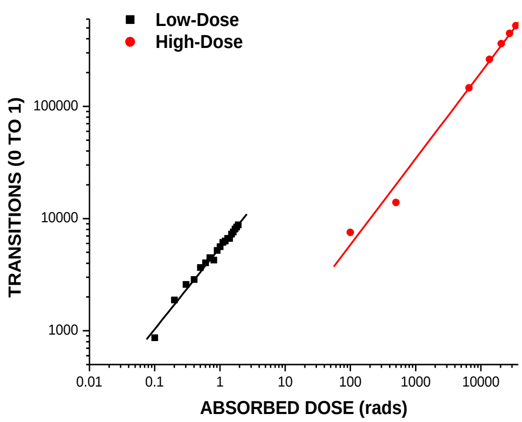

Fig. 5 Similar devices prepared for low-dose and high-dose operations. For low doses, the device is biased while no bias is applied for high-dose operation. Also, the transition region is expanded so that the active transition region covers the entire memory array, thus, greatly increasing the number of flips per unit absorbed dose/