Impact of space weather on flash memory devices

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ABSTRACT

The Microelectronics Testing and Technology Obsolescence Program (METTOP) at New Mexico Tech has been developed for the testing and evaluation of semiconductor devices under a wide range of environmental conditions. Capabilities range from testing microprocessors and large memory devices to power and microwave devices. Combined with radiation facilities at the White Sands Missile Range, a complete testing and evaluation program for microelectronics has been developed. In this paper we report on recent tests of flash memory devices irradiated to failure. This is a prelude to evaluating these devices under simulated space weather conditions. These results demonstrate the suitability of the METTOP facility for testing microelectronic devices.

1.0 INTRODUCTION

The space environment is hard on satellites, space craft and space stations, and particularly harsh on their supporting microelectronic components. The environmental effects are exacerbated as space systems require an emphasis on the use of light weight materials and components that provide little shielding against radiation. In the case of geosynchronous satellite orbits, the normal background radiation environment is composed of cosmic rays, protons and electrons [1]. In these orbits, the most damaging radiation are cosmic rays and protons at energies greater that 30MeV [1], as these can easily penetrate the thin skin of space craft, and high energy electrons. Debris radiation generated from particle interactions with the space craft itself also creates problems for electronic devices [1].

Qualifying microelectronics devices for use in space requires a detailed understanding of the space environment, both normal and abnormal patterns generated by solar phenomenon including coronal mass discharge and solar flares. The radiation environment is measured by various satellites presently in orbit providing a measure of the space weather on a moment by moment basis. While the environment for space weather can be artificially created and devices exposed at various rates and total doses, evaluating these devices can require a significant set of electronic test and evaluation equipment.

The Microelectronics Testing and Technology Obsolescence Program (METTOP) at New Mexico Tech was developed to provide a facility for modern electronic devices. Capabilities range from testing microprocessors and large memory devices to power and microwave devices. Combined with radiation facilities at the White Sands Missile Range, a complete testing and evaluation program for microelectronic devices can be developed.

In this paper we report on our initial tests of a commercial flash memory device in a radiation environment. These preliminary tests were used to understand the radiation exposure needed to create device failures and characterize the component failure. This preliminary work will be followed by future studies that will evaluate devices under simulated space weather conditions.

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2.0 TEST FACILITIES

2.1 METTOP

The METTOP facility was designed to perform electrical testing and evaluation on a wide range of microelectronic components used in both digital and analog systems. A microelectronic laboratory's testing capabilities are heavily dependent on the instrumentation and experience level of the operators and engineers. This has been the underlying axiom throughout the design stage at METTOP. As a result, METTOP has a significant number of advanced testing instruments, for both digital, analog and mixed signal devices, along with the ability to construct ad-hoc testing networks, all supported by significant computer command and control networks.

There are several specialized instrumentation systems available in the METTOP facility including: a Credence Personal Kalos II; an Agilent 4156C Precision Semiconductor Parameter Analyzer; two mainframe testers: a Credence Sapphire and Teradyne A575/A585; and a REMSTAR storage system. In this study the main instrument used was the Credence Personal Kalos 2 system.

Figure 1: Overview of the METTOP test facility, a 3900 square foot facility for evaluation of microelectronic devices.

2.1 CREDENCE PERSONAL KALOS II

Credence PK II, shown in Figure 1, is a desktop engineering test system for testing flash and non-volatile memory devices. The system contains two 48 pin I/O test sites on a single card, with capabilities to test up to 192 pins. It provides an Algorithmic Pattern Generator, a test controller CPU, a data buffer Memory Error Capture RAM, a parametric measuring unit and redundancy analysis for every site. In addition to memory devices it is also capable of testing logic, microprocessors, and some mixed signal devices.

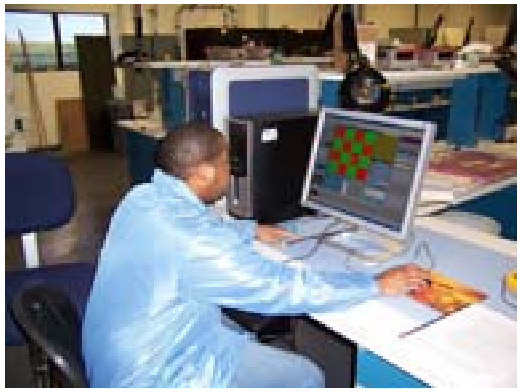

Figure 2: METTOP engineer in the process of validating a 4 Mbit (512K x8) SuperFlash EEPROM using a checkerboard pattern test.

Computerization of many military systems has pushed forward the need for extensive testing of digital components. In particular microprocessor and memory components require careful evaluation, particularly if being used in radiation environments such as those seen in satellite systems.

The Credence PKII shown in Figure 3 is configured for evaluating memory chips.

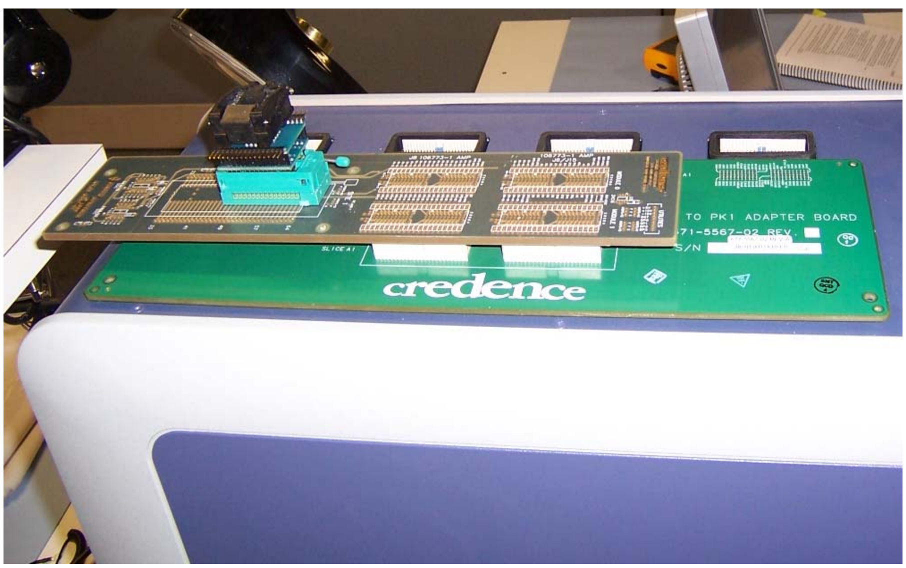

Figure 3: Top view of the Credence PKII with a memory chip test board attached.

2.2 RADIATION TESTING AT WHITE SANDS MISSILE RANGE

The irradiation facilities at White Sands Missile Range include gamma, electron and neutron systems. These facilities can be used for bulk device testing or a low number of devices that are operating under bias.

One indicator of radiation affecting a semiconductor device is changes in the quiescent current. Using the facilities at the White Sands Missile Range it is possible to test devices under bias, so the quiescent current through the device is monitored during the actual irradiation. In addition, total dose and single event latch up effects on the devices [2,3] were evaluated. The radiation sources available for use at White Sands Missile Range are a LINAC, to provide a source of energetic electrons; a fast burst reactor, to provide a neutron flux; and gamma radiation from a Co^{60}

source. The Enhanced Low Dose Rate Sensitivity (ELDRS) facility, which provides a constant low radiation, will eventually be used to provide long period, low dose radiation to simulate the effects of a space environment.

2.3 SPACE RADIATION ENVIRONMENT

There are a number of models that describe the space radiation environment at various orbital locations. In addition, several satellites provide real measurements of the radiation flux for their orbital positions.

The space radiation environment is composed of protons, neutrons, electrons and gamma rays. This environment can be simulated using several different radiation sources, though it is complex to provide the complete environment during a single test. As a result, device testing usually relies on simulating the radiation environment using one or two radiation sources in a given test.

The dose rate and total dose that a device can expect to encounter in space can be calculated from models or compared directly to data gathered from existing satellites that monitor the radiation levels at their orbital locations [4]. Figure 4 shows electron radiation data from the GEOS satellite system.

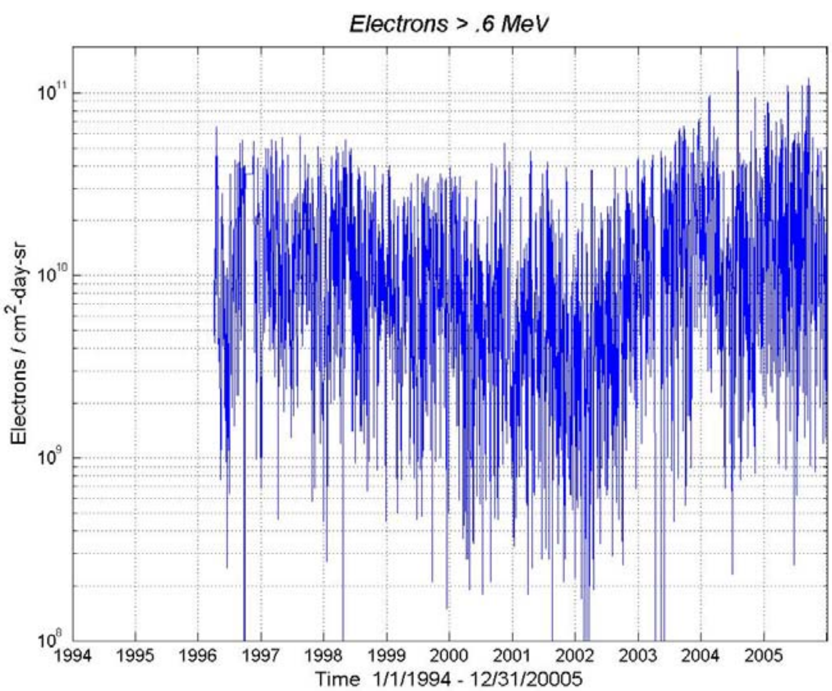

Figure 4: Electron flux measured at the GEOS satellites over the period from 1996 to late 2005.

Integrating the GEOS data provides the total dose that the detectors on the satellite have accumulated over the recording period. The running total of the accumulation is shown in Figure 5. This data set allows the instantaneous and average dose rate to be evaluated and included in future simulations.

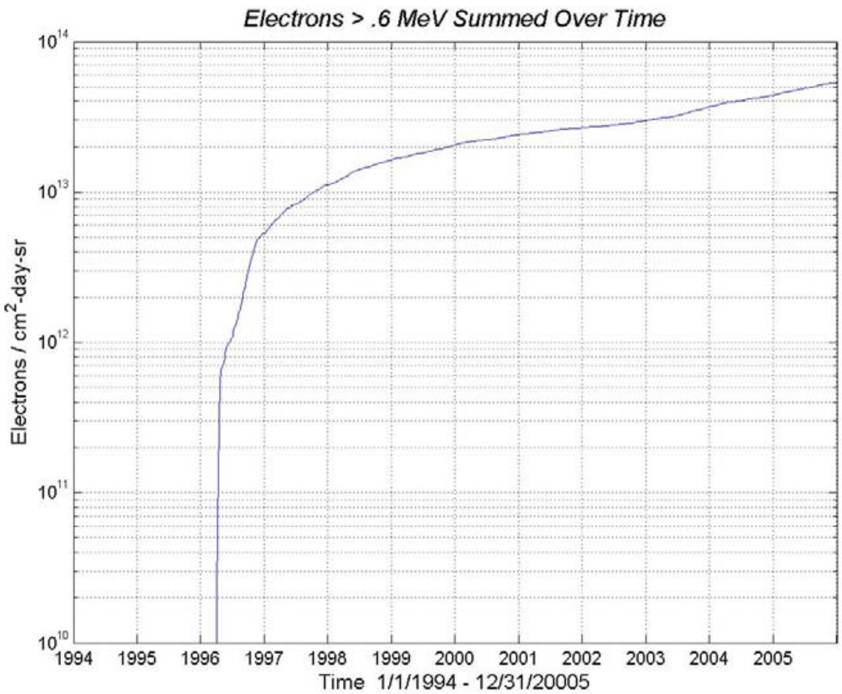

Figure 5: Sum of the Electron flux greater than 0.6 MeV in energy measured at the GEOS position over the period of 1996 to late 2005. The rise at the start of the data is an artifact of the start date.

3.0 EXPERIMENT

In this experiment the performance of a parallel readout flash memory device under several total dose irradiations was evaluated. The objective is to take the device to failure and identify the indicator for the failure. The device is a 4 Mbit serial readout, CMOS split-gate cell EEPROM. This device is interesting as it is a relatively new device, designed to have better reliability and manufacturability than previous devices, and can be used as a major component of a microprocessor system.

Radiation testing is time consuming and the radiation facilities at White Sands Missile Range are in high demand. This required that the experiment be restricted to a limited number of devices and that the pre and post - radiation testing be performed off site using the METTOP facilities. A statistical sampling of the EEPROMS was obtained by testing 21 devices.

Pre-radiation evaluation was completed at METTOP using a Credence Personal Kalos II (PKII) memory tester. Both parametric and functional tests were performed on each of the devices. The parametric tests done were opens and shorts (to test for continuity and make sure no pins were shorted together) and input/output leakage current high, input/output leakage current low, and an ICC test. For functional testing, certain patterns were written to the chip to make sure data could be written properly. Patterns used were a checkerboard pattern and a stripes pattern. A chip erase cycle was also conducted to make sure the data could be erased properly.

The irradiation and live testing was performed at White Sands Missile Range in the Nuclear Effects Facility using the same PKII. The gamma range at WSMR uses a Co60 source to create gamma radiation. It irradiates at a rate of up to 1000 Rad/sec. We irradiated a sampling of parts using the gamma source at dose rates of 100rads/sec to total doses of 5, 10, 25, 30, 40, 45 and 50 krads. The gamma rays from Co60 have main energy lines of 1.17 and 1.33 MeV [4]. While these lines are not ideally suited for simulating the space environment, this source will provide a demonstration of the failure of the EEPROM under irradiation.

4.0 RESULTS

The quiescent current was monitored as the parts were irradiated in the Co60 beam. The total dose is show on the x-axis of the plot shown in Figure 6. A significant change in the quiescent current was observed when the total dose reached 45krads.

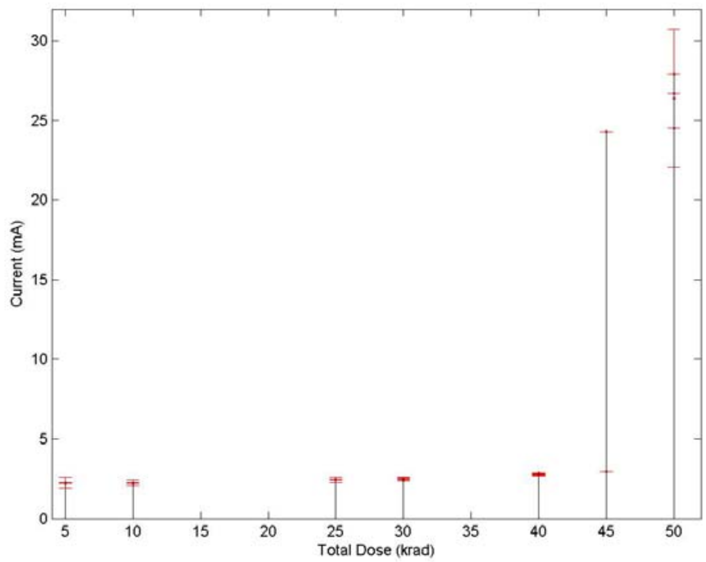

Figure 6: Quiescent current plotted against the total dose applied to the device.

Post irradiation, the parts irradiated to 40 kRads and beyond were examined using the PK2 to determine the effect on the performance of the memory cells. Figure 7 shows that the devices irradiated to 40krads and beyond showed failure in the performance of the memory cells indicated on the PKII by an inability to read and write from these memory cells.

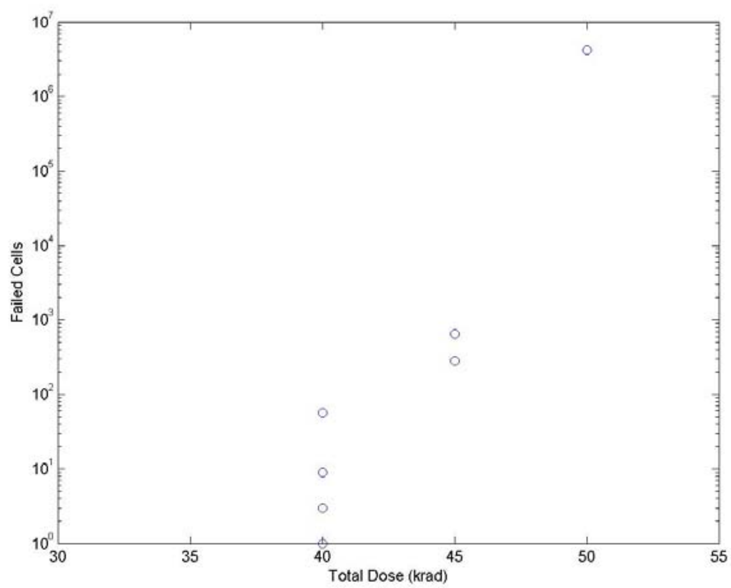

Figure 7: Plot of the number of failed cells with total applied dose.

5.0 CONCLUSIONS

METTOP is an advanced microelectronics facility developed to support the testing, evaluation and analysis of devices used in military, legacy and future combat systems, and space applications. METTOP's unique suite of instrumentation and access to device stressing facilities makes it possible to perform advanced testing required to evaluate device performance over a wide range of conditions.

Initial evaluation of the EEPROM show that the devices show degraded performance under total dose levels above 30krad. This can be seen as a change in the quiescent current during irradiation and demonstrated as read / write errors in post irradiation testing.

ACKNOWLEDGEMENTS

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