TID Testing of Ferroelectric Nonvolatile RAM

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Abstract— The test results of measurements performed on two different sizes of ferroelectric RAM (FeRAM) suggest the degradation is due to the low radiation tolerance of sense amplifiers and reference voltage generators which are based on commercial CMOS technology. This paper presents TID testing of 64Kb Ramtron FM1608 and 256Kb Ramtron FM1808.

I. INTRODUCTION

Ferroelectric memories have received more research attention in recent years. In term of the number of inventions granted by the U.S patent office, there were 120 for the year of 1999 alone. Fast programming time with low power consumption and the rising demands of smart cards and digital cameras have driven the recent activity. In addition, many deep spaces and near earth missions are looking for alternatives to traditional non-volatile memory. Floating-gate memories such as flash memories and EEPROMs with larger storage capability currently dominated the digital camera applications are due in part to its mature process technology. But ferroelectric memories possess superior features over floating-gate devices. These are write-access time and overall power consumption [1]. Table I compares flash memories, EEPROMs and ferroelectric memories. Digital cameras for use in future space rovers and miniature smart instruments will benefit from the fast frequent writes and low power usages of ferroelectric memories.

TABLE I

Comparison of Nonvolatile Memories

	FeRAM	EEPROM	Flash
Write (ns)	100	10^6 - 10^7	10^4 - 10^5
Write Voltage	1-3V	12-18V	12-21V
Write cycles	$>10^{12}$	10^5	10^5 - 10^6
Overwrite	Yes	No	No

In addition to fast write requirements, battery-less smart cards operate from power supplied by an r-f signal from the card reader.

II. DEVICES DESCRIPTIONS

A. Ferroelectric Technology

The ferroelectric effect is characterized by the remanent polarization that occurs after an electric field has been applied. The unique chemical atomic ordering of these materials allows a single ion to change its physical location. Figure 1 shows simplified models of a ferroelectric material. The center atom (zirconium or titanium) will move into one of the two stable states upon an external applied electric field. After the external electric field is removed, the atom remains polarized in either state; this effect is the basis of the ferroelectric as a nonvolatile memory. An electric field can reverse the polarization state of the center atom, changing from a logic state “0” to “1” or vice versa.

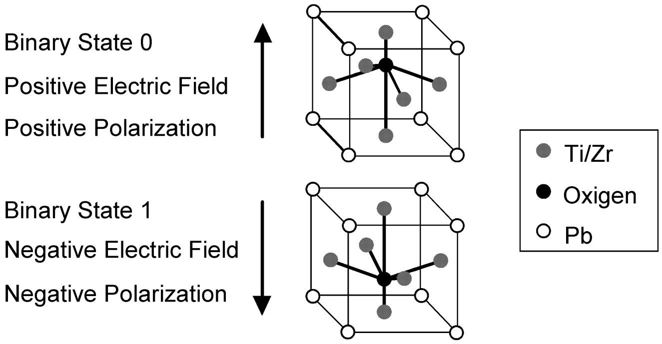

Fig 1. Two stable states in a ferroelectric material

The ferroelectric thin-film material of RAMTRON product is lead-zirconate-titanate (PZT). Figure 2 shows the hysteresis loop exhibited by a PZT ferroelectric capacitor. The total charge for a relaxed “0” state is Q_r and $-Q_r$ for a relaxed “1” state. By applying a negative voltage across the capacitor, a “0” state can be changed to “1”, and consequently the total charge on the capacitor is reduced by $2Q_r$. With a positive voltage across the capacitor, a “1” can be switched back to “0”, and the total charge restores to $+Q_r$. The nonvolatile polarization, P_{nv}, is the difference

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between the relaxed states, the charge density that can be sensed by the sense amplifier circuitry.

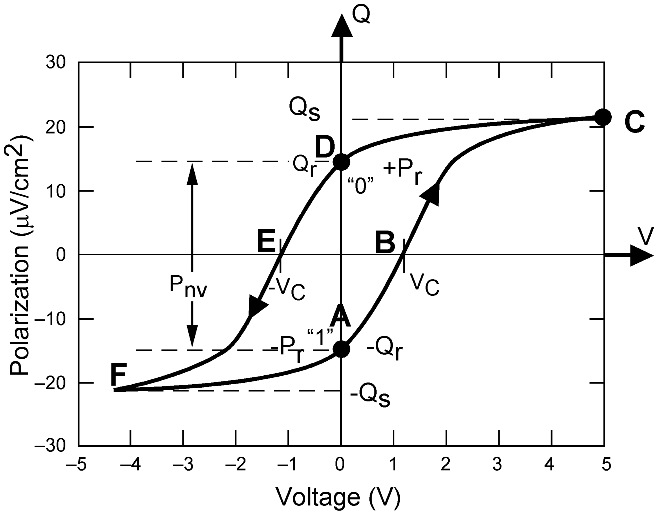

Fig 2. Hysteresis loop characteristic of a ferroelectric capacitor. Applying V_{cc} = 0 to the ferroelectric capacitor results in points D and A. The remanent polarization charge is +P_r or –P_r allowing binary data to be stored.

Ramtron FM1608 and FM1808 are built using 2 transistors/2 capacitor bit cells (2T/2C) structures as shown in Figure 3. A sense amplifier connected to the bit lines reads the output by measuring the difference of charge transferred from the two cells. In read operation, BL must be precharged to 0V. WL is selected and PL is pulsed to +V_{cc} or to the "C" state as marked in Figure 2. If the cell holds "0" state, the polarization is not reversed but the slight movement of the electric charge causes BL to charge up by .V_1 . Since no reversal of polarity occurs, the data is not destroyed and a "0" state is retained. If the cell holds "1" state, polarization is reversed, causing a large amount of charge goes to the bit line BL. When reading "1" data, the reversed polarization creates "0" logic state or destroyed the initial data. After the reading of "1" data takes place, the voltage on the bit line is at V_{cc}. The PL voltage level is at 0V, restores the correct "1" data to the cell. The plate line is usually pulsed to supply both polarities of write signals to the capacitor [2].

B. Device Descriptions

The RAMTRON FM1608 is organized as 8,192 x 8 bits and the FM1808 as 32,768 x 8 bits Ferroelectric Nonvolatile RAM. Both parts operate internally at Vcc of 5.0 volts during the erase and write processes. During the write operation, the required electric field needs to polarize the nonvolatile elements takes about 100ns. The entire memory operation occurs in a single bus cycle and therefore there is no data-polling requirement. The memory array of FM1808 is divided into 32 blocks of 1k x 8 each. The FM1608 has 8 blocks of 1k x 8 each. Each block of 1k x 8 consists of 256 rows and 4 columns.

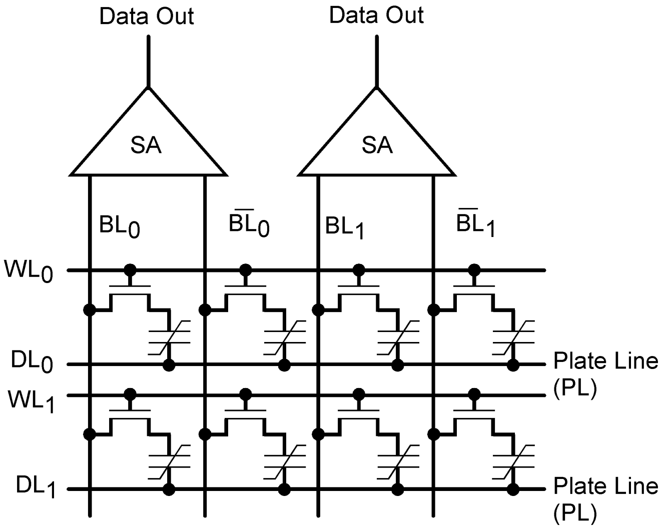

Fig 3. 2-transistor/2-capacitor cells architecture

III. TEST RESULTS

A. Test Approach

Two dose rates were used: a high dose rate of 50 rad(Si)/s and a low dose rate of 0.0116 rad(Si)/s. One test configuration was to expose devices with no bias at a high dose rate. Other tests were to irradiate devices with static biased where all pins were connected to V_{cc} = 5.0 volts. Electrical measurements were made with the Advantest test system T3342. Data of the following parameters were recorded between radiation levels: standby current I_{sb}, input currents I_{ih} and I_{il}, and functional tests. Devices were programmed with a checkerboard pattern, and then were verified for the integrity of the test pattern. The DUT power supply voltage was removed, and then reconnected for the read operation to test the nonvolatile data. If less than 10 read errors were detected, the failed parts were reprogrammed for the next exposure.

Four devices of each part type also were irradiated with protons. The facility used in this experiment is the accelerator at the University of California at Davis. Standby, read and program currents were recorded between radiation levels. They were programmed with all zeros, then all ones, and finally with checkerboard. Before and after each exposure, the nonvolatile data were verified by going through the power off/on and read sequence.

B. TID Results

Both RAMTRON device types had very similar test results when exposed with the 50 rad(Si)/s dose rate. They performed normally at 10 krad(Si), but started having read errors at around 12.5 krad(Si). They stopped to function at 25 krad(Si) and did not recover after 24 hours at 100C annealing process. Both device types standby currents increased rapidly after 10 krad(Si) when irradiating with Co-60, and after 15 krad(Si) with protons.

1. FM1608 devices:

1.1 High dose rate (50 rad(Si)/s):

The 64Kb FeRAM devices were irradiated at the following dose levels: 5 krad(Si), 7.5 krad(Si), 10 krad(Si), 11.25 krad(Si), 12.5 krad(Si), 25krad(Si) and 50krad(Si). Figure 4 shows the devices function well past 10 krad(Si). They started having read errors around 12.5 krad(Si) when the standby current went into the mA range. But after rewriting with the same pattern, the parts were functional again. At 25krad(Si), devices failed to read all 8,192 cells. DUTs were programmed with all zeros and then read back. None of the 8,192 locations had registered a “0” state. At 50krad(Si), the input current I_{ih} was marginally over the specifications limit of 10µA, precisely at 12.3µA.

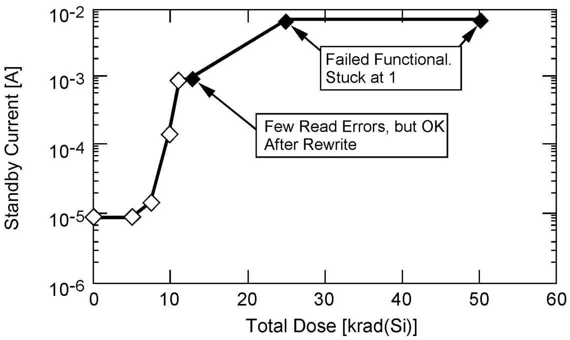

Fig 4. TID effects on 64Kb FeRAM at 50rad(Si)/s

Figure 5 shows standby currents of two post-irradiated DUTs after more than 100 hours unbiased anneal versus the number of write/read cycles. Serial number 4278 part had 2 read errors prior to the cycling test. The two read errors stayed until the end of the 9 millionth cycles. The relative, short 9 million cycles had no effect on the irradiated FeRAM devices. As stated in Table I, the FeRAMs can be write/read over 10^{12} times. With the clock rate of 200ns, it would take 8 hours to cycle through 1 million write/read operations for the 64Kb FeRAM. It will take four times longer for the 256Kb FeRAM to go through the same number of write/read.

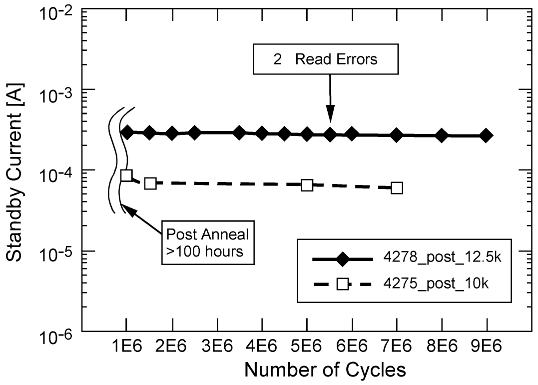

Fig 5. Standby current vs. cycling of FM1608

1.2 Low Dose rate (0.0116 rad(Si)/s):

Three samples were irradiated and electrically tested at different dose levels: 1, 2 ,3, 6, 9, 15, 16, 20, 21, and 22 krad(Si). Two devices failed to read checkerboard and to write “0” after 20 krad(Si). Device serial no. 4508 annealed and it could be programmed with fewer errors. Figure 6 shows the response of FM1608 standby currents to Co-60.

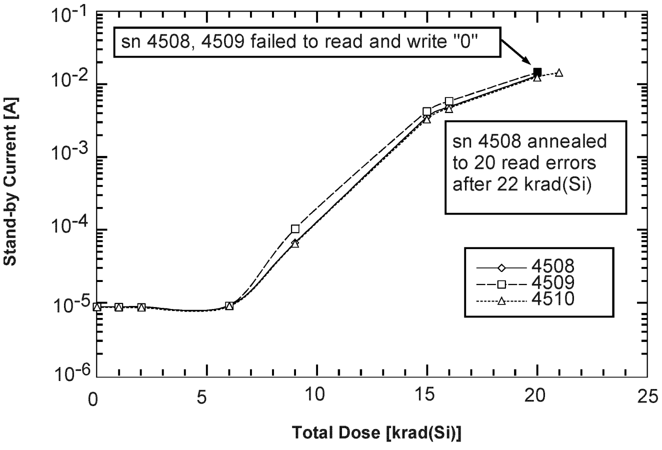

Fig. 6 TID effects on 64Kb FeRAM at a low dose rate.

1.3 Protons:

Two devices were filled with “0”, “1”, checkerboard and verified, then powered off before exposing to protons source. In between the following levels, the devices were powered and read back: 2, 4, 6, 8, 10, 15, 20, 25 krad(Si). The traces of figure 7 illustrate the standby and operating currents. After 15 krad(Si), the standby current increased rapidly. After 25 krad(Si), both devices failed to write data.

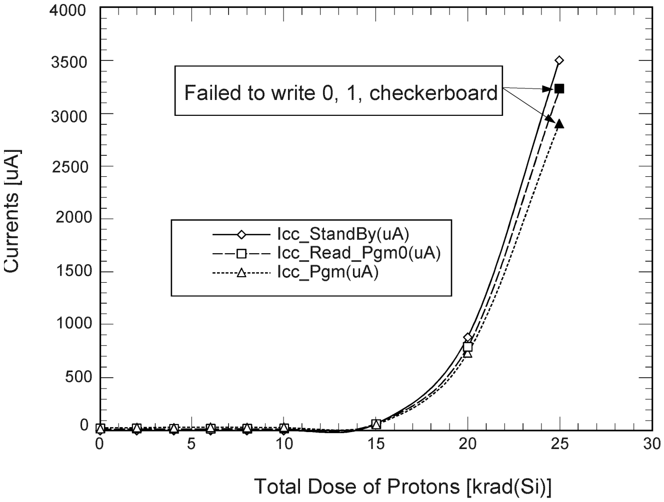

Fig 7. Response of 64Kb FeRAM to protons

2. FM1808 devices:

2.1 High dose rate (50 rad(Si)/s):

The 256Kb FeRAMs were exposed at the following dose levels: 5 krad(Si), 7.5krad(Si), 10krad(Si), 12.5krad(Si), and 25 krad(Si). Figure 8 illustrates its response of standby currents versus total doses. Like the FM1608 parts, DUTs passed at 10 krad(Si) with standby current recorded under 20 µA. Three read errors were observed at 12.5 krad(Si) and standby current increased to the 100 µA range.

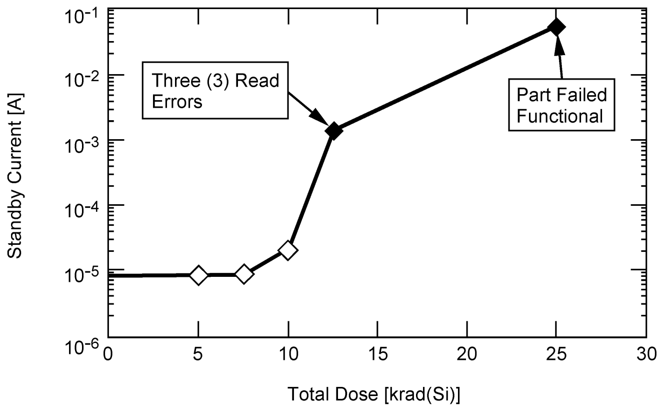

Fig 8. TID effects on 256Kb FeRam at a high dose rate

2.2 Low dose rate (0.0116 rad(Si)/s)

Additional low dose rate testing was performed on three samples. Figure 9 shows the response of standby currents versus doses at different levels. At 15 krad(Si), all three devices failed to retain expected data. The devices were reprogrammed and read to verify that the expected data were written. After the power was off for one minute, the devices were read for data retention. They failed to read at the same locations. At 16 krad(Si), part serial number 4511 failed to be written with zeros. All three devices could not be programmed with zeros after 19 krad(Si).

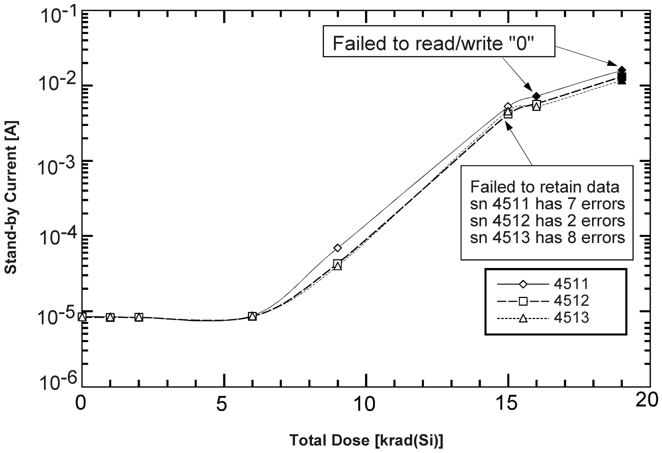

Fig 9. TID effects on 256Kb FeRAM at a low dose rate

2.3 Protons:

Two devices were tested with protons. Three types of currents were recorded: standby, read and program. One device failed to program all "1" and the checkerboard pattern after 20 krad(Si). Both stopped functioning after 25 krad(Si).

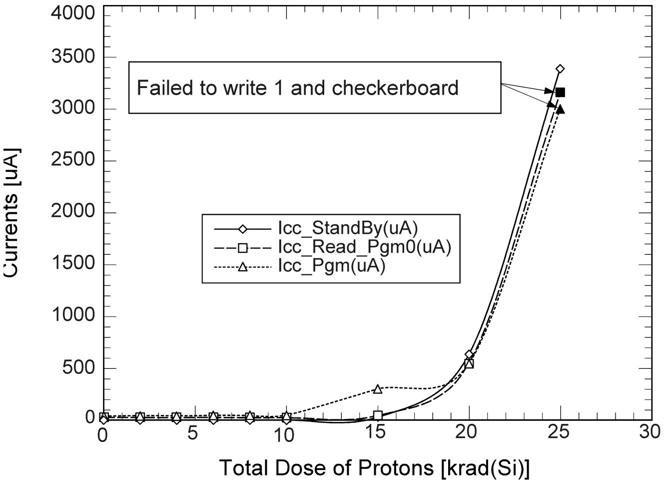

Fig 10. Response of 256Kb FeRAM to protons

2.4 No bias during irradiation:

Some JPL projects turn on critical subsystems only when required to minimize the risk of exposing sensitive devices to radiation. Without any biased condition during exposures, the CMOS FeRAM devices still perform in the mega-rad(Si) range of gamma rays as shown in Fig 11. The latest data indicates that the devices still function after the 7 Mrad(Si) level.

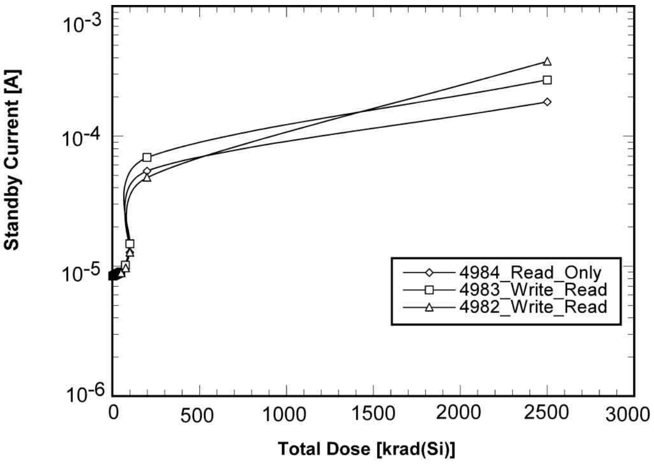

Fig 11. Response of 256Kb FeRAM with unbiased setup

IV. CONCLUSIONS

The FeRAMs start having read problems at around 12 krad(Si) and cease to function at the 25 krad(Si) level. Since writing to FeRAM cells is a direct overwrite process, there is no pre-erase and polling to keep track of how many write errors accumulated during the programming stage. Ferroelectric thin films have been seen to be inherently resistant to ionizing radiation [3], [4]. Observed read errors may indicate that sense amplifier circuits are affected by radiation. The control circuitry may not provide the appropriate voltage levels to restore data after destructive reads.

V. REFERENCES

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