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 space and near earth missions are looking for alternatives to traditional **NVM.** 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 remnant 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 ot 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.

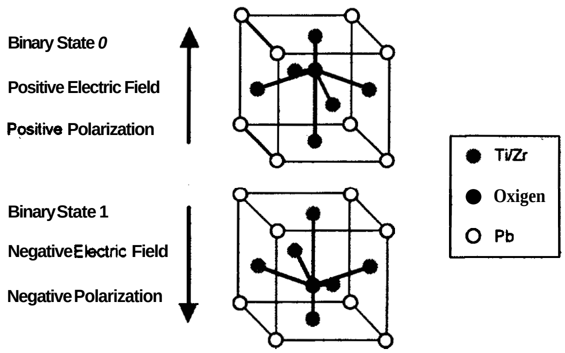

Fig 1. Two stable states in a ferroelectric material

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.

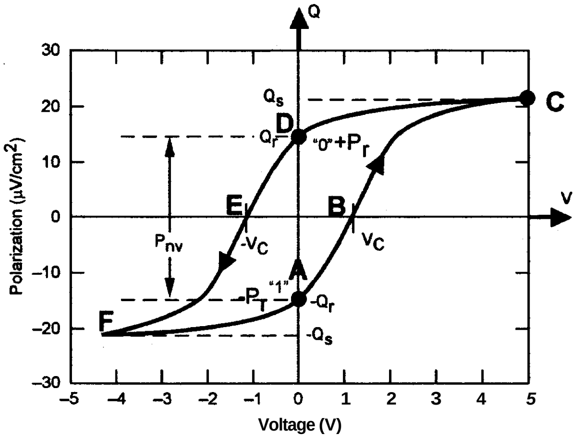

Fig 2. Hysteresis loop characteristic of a ferroelectric capacitor. Applying $V_{cc} = 0$ to the ferroelectric capacitor results in points D and A. The remnant polarization charge is $+P_r$ or $-P_r$ allowing binary data to be stored.

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 OV. 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 to go 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 OV, 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]. The 2T/2C structure is inherently reliable but at the expense of device real estate.

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.

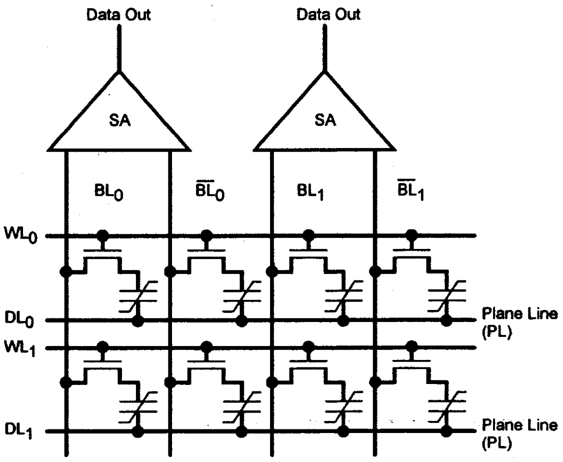

Fig 3. **2-transistor/2-capacitor** cells architecture

III. TEST RESULTS

A. Test Approach

Three devices of each part type .were irradiated with Co-60 at room temperature with a static biased configuration. 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. Devices then were placed in the Co-60 chamber and were irradiated at 50 rad(Si)/s at **V„** = 5.0 volts.

B. TID Results

Both RAMTRON device types had very similar test results. 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 went upward rapidly after 10krad(Si).

1. *FM1608 devices:*

The 64Kb FeRAM devices were irradiated at the following dose levels: 5 krad(Si), 7.5krad(Si), 10krad(Si), 11.25 krad(Si), 12.5 krad(Si), 25krad(Si) and 50krad(Si). Figure 4 shows the devices function well pass 10 krad(Si). They started having read errors around 12.5 krad(Si) when the standby current went into mA range. But after rewrite 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} is marginally over the specifications limit of **10μA,** precisely at 12.3μA.

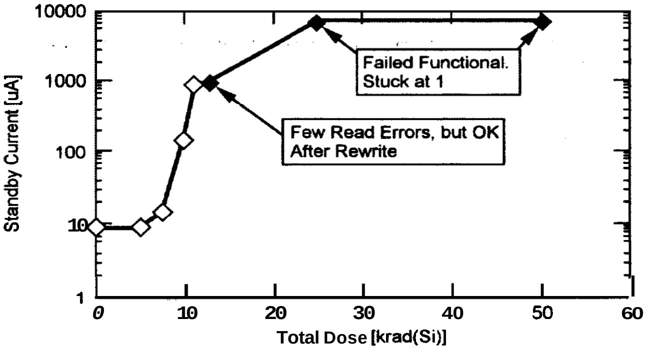

Fig **4. Standby Current vs. Total Dose** of **64Kb** FeRAM

Figure 5 shows standby currents of two post-irradiated **DUTs** after more than 100 hours unbiased room temperature 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.

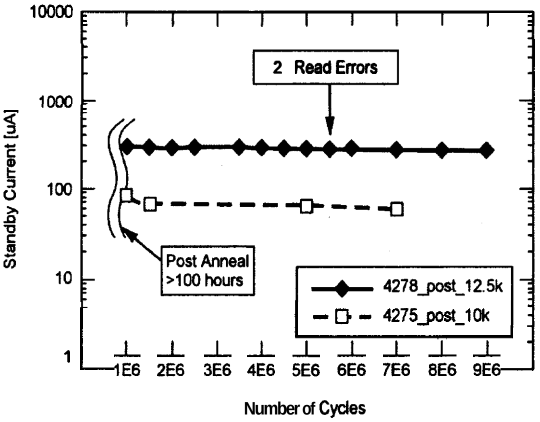

Fig **5. Standby current vs. cycling of FM1608**

2. *FM1808 devices:*

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 6 illustrates its response of standby current versus the total dose. 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 started going upward to 100 μA range.

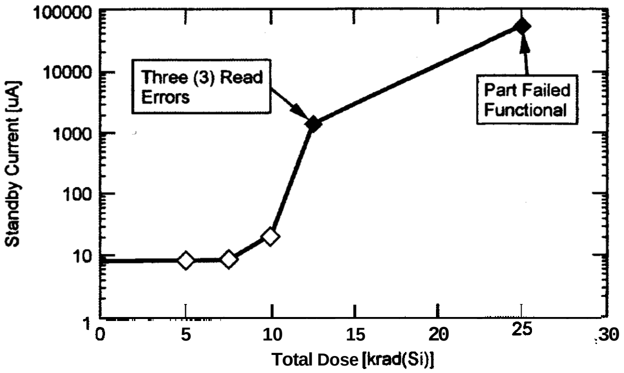

Fig **6. Standby current vs. Total** Dose of **256Kb** FeRAM

IV. CONCLUSIONS

The FRAM is affected and seems to have TID problems at around 12.5 krad(Si) and ceases to function at 25 krad(Si). Since writing to FeRAM cells is a direct overwrite process, there is no pre-erase and polling to monitor and keep track of how many write errors accumulated during programming. Ferroelectric thin films have been seen to be inherently resistant to ionizing radiation [3]. In order to operate normally in a radiation environment, ferroelectric technology will need to combine with a radiation hardened CMOS process in order to withstand higher **TID** levels. Samples **of** devices of large sizes, 1Mb to 32Mb are being procured. Samples from other manufacturers also are being investigated.

V. REFERENCES

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