Preliminary Evaluation of Data Retention Characteristics for Ferroelectric Random Access Memories (FRAMs).

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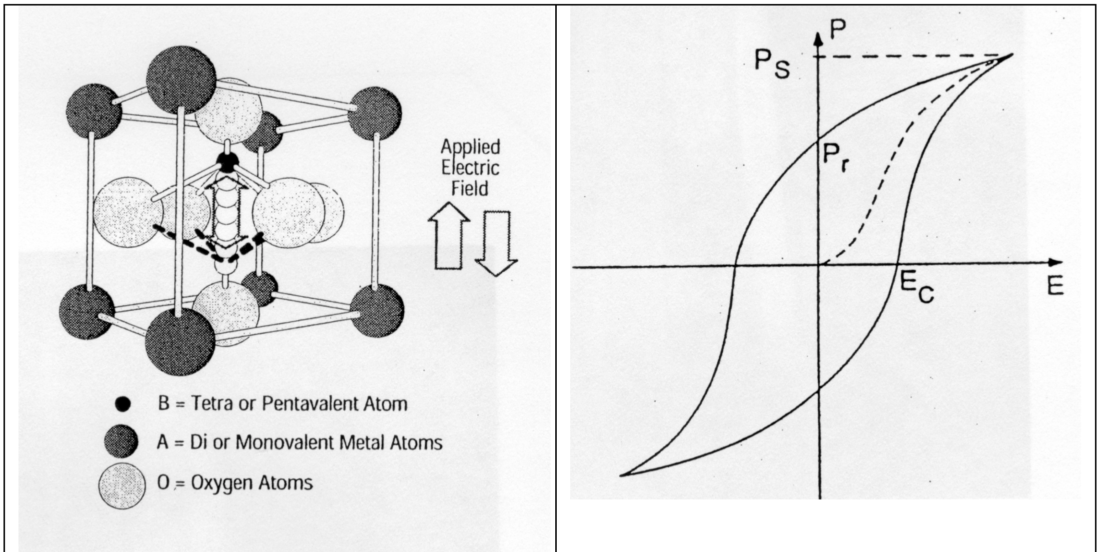
1.0 Introduction

1.1 FRAM Technology Background

Ferroelectric memory (FRAM) is a RAM-based device that uses the ferroelectric effect as the charge storage mechanism, and is very different from the floating-gate based nonvolatile memories. The ferroelectric effect is the ability of material to store an electric polarization in the absence of an applied electric field. A FRAM memory cell is fabricated by depositing a film of ferroelectric material in crystal form between two electrode plates to form a capacitor, which is very similar to a DRAM capacitor. However, instead of storing data as charge on a capacitor like a DRAM, a ferroelectric memory stores data within a crystalline structure. The Petrovskite crystals of the ferroelectric material maintain two stable polarization states resulting from the alignment of internal dipoles, corresponding to states of logical "1" and "0". The application of an electric field that exceeds the coercive field of the material will cause this alignment, while the reversal of the field reverses the alignment of these internal dipoles.

A simplified model of a ferroelectric crystal is shown in Figure 1(a) [1]. It has a mobile ion in the center of the crystal, and applying an electric field across the face of the crystal causes this ion to move in the direction of the field. A reversal of the field causes the ion to move in the opposite direction. The ion position at the top and bottom of the crystal are stable, and the ion remains in these states when the external field is removed. Since no external electric field or current is required for the ferroelectric material to remain polarized in either state, a memory device can be built for storing digital (binary) data that will not require power to retain information stored within it. Typical perovskite ferrolelectric materials are $BaTiO_3$, $PbTiO_3$, PZT($PbZr_{1-x} Ti_xO_3$), PLZT($Pb_{1-x}L_xZrO_3$), PMN($PbMg_{1-x}Nb_xO_3$), SBT($SrBi_2Ta_2O_9$), SBN($SrBi_2Nb_2O_9$), etc [2].
Figure 1(b) shows a typical hysteresis curve of a ferroelectric capacitor and the response of the polarization (P) to the externally applied electric field (E).



a) b)

Figure 1. A ferroelectric material (a) Perovskite crystal unit cell, and (b) Typical hysteresis curve

1.2. FRAM Reliability Issues

Data retention, which is defined as the ability to maintain stored data between the time of writing and subsequent reading of the stored information, is one of the most important characteristics of the non-volatile memory devices. Retention failures, as well as failures due to the time dependent dielectric breakdown and leakage currents in memory cells are known failure mechanisms in all non-volatile memory devices, including FRAMs.

Test data on low density Ramtron FRAMs has demonstrated the failure rate of less than 60 fits with a 60% confidence level for 10-year data storage at room temperature [3]. However, the retention characteristics depends on multiple manufacturing and design factors and remain a major concern for reliability evaluation of new generations of FRAMs. Temperature, significantly accelerates retention failures due to thermal depolarization of the poled state in the ferroelectric material. In addition to retention failures, there are other failure modes and mechanisms that are specific to ferroelectric memory cells such as fatigue, aging, imprint, failures caused by reducing-environment conditions and radiation.

The major objective of this task was to evaluate reliability of FRAMs (with a focus on data retention characteristics) for their potential usage in space applications.

2.0 Part Description

Fifty FRAMs in ceramic 28-DIP packages (FM1608S-250CC) and fifty microcircuits in 28-DIP plastic packages (FM1608-P) manufactured by Ramtron were used for this evaluation. The FM1608 is a 64 Kbit, nonvolatile memory; organized as 8,192 x 8 bits that uses an advanced ferroelectric process. Functional operation of the FRAM device is similar to an SRAM. The users can access 8,192 memory locations, each with 8 bits through a parallel interface. The complete address of 13-bits specifies each of the 8,192 bytes uniquely. Internally, the memory array is organized into 8 blocks of 1 Kb each. The three most significant address lines decode one-of-eight blocks. Figure 2 shows the block diagram, pin description and functional truth table for the FM1608.

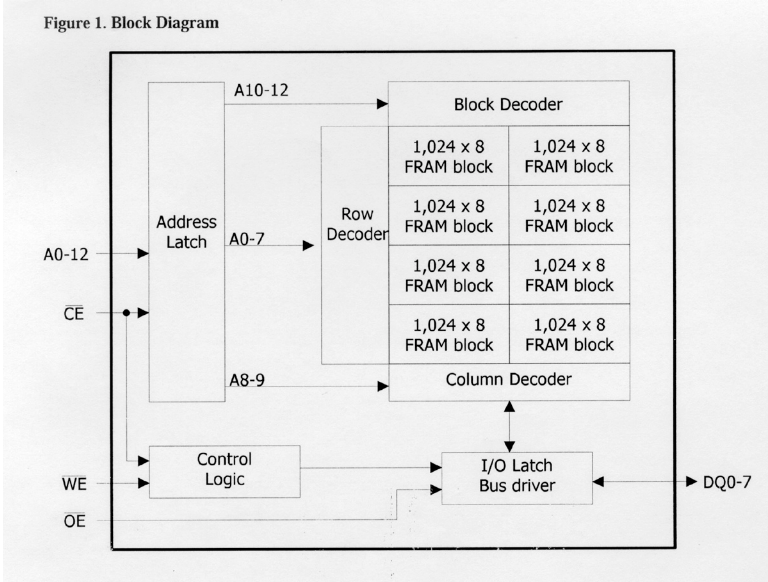


Figure 2. FM1608 Block diagram.

3.0 Test Description

A total of 100 parts, 50 each of ceramic 28-pin DIPs and plastic 28-pin DIPs were divided into various groups and subjected to high temperature storage aging tests at 150 °C, 175 °C, 200 °C*, 225 °C*, 250 °C*, and 275 °C* (* ceramic packages only) for several thousand hours cumulative, with interim and final electrical measurements (EM) for each lot. A high temperature, step-stress test was performed to estimate the temperature range, which causes high rate of retention failures. Low temperature exposure testing was performed on a lot of parts at – 85°C. Temperature cycling was performed between – 65°C and +150°C for 425 cycles with interim and final EM. In addition, extensive read-write cycling, and total dose ionizing radiation testing was also performed on some lots of parts.

Electrical measurements were performed using HP82000 digital tester and included parametric and functional measurements. The parametric measurements included input and output voltages and leakage currents (VOL, VOH, IIL, IIH, ILO_L, ILO_H), stand-by and active power supply currents (ICCSB_cmos, ICCSB_ttl, ICCOP) and chip enable access time (tCE). During the functional testing, six data patterns (“scan 1”, “scan 0”, “check error board” and three pseudo-random patterns) were consequently written and then read for each test sample. The functional test frequency was 1 MHz.

To evaluate retention characteristics of the parts, each sample was subjected to parametric measurements and then to the functional testing with the pseudo-random pattern 1 (PRP1). Electrical measurements after the parts had been stressed for a specified period of time (retention period) at specified environmental conditions started with reading the PRP1 and followed by the parametric measurements. All parts passed initial characterization testing consisting of radiography and PIND testing, and then were preconditioned by 10,000 write-read cycles. No failures during preconditioning and/or initial electrical measurements were observed.

4.0 Temperature Dependence of Data Retention Time

Based on data obtained from high temperature aging test, a proportion of failed vectors was plotted with time on a Weibull probability chart (see Figure 3). The data can be approximated with two lines: a low-slope line ($\beta << 1$) at relatively low retention times and a high-slope line with $\beta > 1$ at large retention times. The low-retention-time failures are due partially to the intermittent failures, whereas the high-retention-time failures (high-beta lines) are due to "intrinsic" failures of the FRAM cells caused by a thermally activated loss of polarization. Extrapolation of the high-beta lines allows for estimation of the median time-to-failure for a vector. These data are plotted on the Arrhenius chart in Figure 4. It is seen, that the retention medium time-to-failure follows the Arrhenius law:

$$MTTF = A*\exp(E/kT)$$

with an activation energy E = 1.05 eV. Extrapolation to normal conditions shows that the MTTF for a vector exceeds 10^4 years at room temperature. The number of vectors in 64K FRAM is 8192, which corresponds to the MTTF of more than 280 years at room temperature.

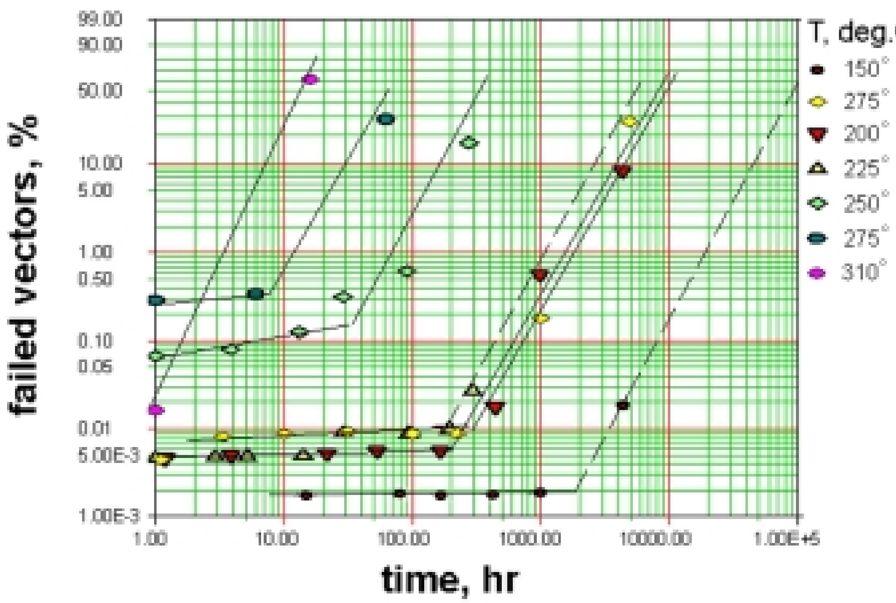


Figure 3. Cumulative proportion of failed vectors in ceramic parts.

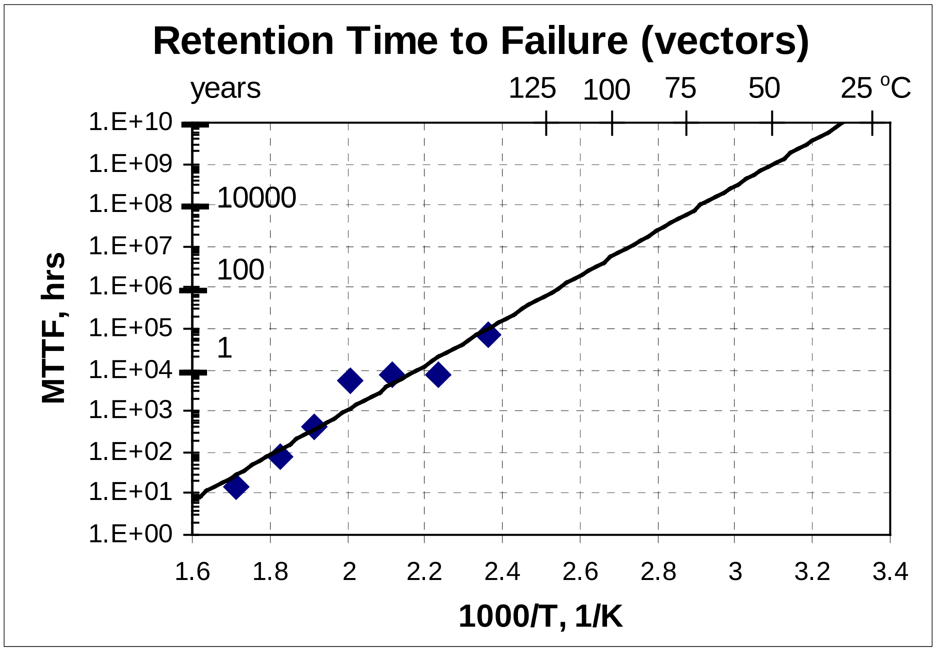


Figure 4. Temperature dependence of the medium time-to-failure.

5.0 Conclusions

Test results and conclusions are summarized below. For details, refer to complete report being posted on the NEPP web page.

1. Retention characteristics of 64k FRAM microcircuits were characterized in temperature range from -85°C to +310 °C during retention periods, up to several thousand hours with the following results:
   1.1. No parametric or functional failures (when the reading immediately followed the writing) occurred during multiple ceramic and plastic parts testing at aging temperatures below 250 °C.

   1.2. Observed retention test failures can be divided in three categories:
   - Random failures, which are not related to stress conditions. Plastic parts had approximately 15 times higher probability of similar failures.
   - Weak cell failures, which were also not related to a stress condition, but were reproducible from test to test. One-two failed vectors systematically appeared in some parts during the aging tests. Similar failures could be screened out by implementing a high temperature data retention test.
   - Intrinsic failures, which were caused by a thermal degradation of the ferroelectric cells. Similar failures occurred in ceramic parts after tens or hundreds hours of aging at temperatures above 200 °C. An estimated activation energy of the retention test failures is approximately 1.05 eV, and the extrapolated mean time to failure at room temperature is more than 280 years.

1.3. No parametric or functional failures of ceramic or plastic parts were detected during multiple (up to 425 cycles) temperature cycling from –65 °C to +150 °C. Both type of parts (ceramic and plastic) withstood retention test with 285 temperature cycles between writing and reading.

1.4. Retention test at –85 °C did not reveal any intrinsic failures. However, some random failures occurred both in ceramic and in plastic parts. The long-term storage (more then 5000 hrs retention time) of the parts did not result in any parametric or functional degradation.

1.5. No retention, parametric, or functional failures occurred with ceramic parts during radiation tests (total dose 90 krad Si). Plastic parts had some random data retention test failures.

2. Operational current measurements with different patterns allow for estimation of the levels of switching and non-switching polarization in the ferroelectric cells. The difference between these two currents depends on the average remnant polarization and can be used for monitoring degradation processes in the memory cells. However, additional analysis should be performed to reliably establish the relationship between the operational currents and the level of cell polarization.

3. Multiple write-read cycling (up to $3x10^7$) during fatigue testing of the plastic and ceramic parts did not result in any parametric of functional failures. However, operational currents linearly decreased with the logarithm of number of cycles, thus indicating fatigue process in the PZT films. This process was accompanied with approximately 20% decrease of the data access time in ceramic parts. Plastic parts manifested significantly smaller changes in operational currents and data access times, which could be due to the different die lot (improved process) used in manufacturing of these parts.

4. Test results confirmed that the PZT-based FRAM microcircuits potentially may have very high data retention and virtually fatigue-free characteristics over a wide interval of temperatures and write-read cycles. This, as well as a high radiation tolerance makes this devices an attractive technology for space applications. However, further improvements in the manufacturing process and/or testing and screening systems are necessary to detect and eliminate devices susceptible to random soft failures.

References

[1]. Ramtron Application Note: FRAM   Technology Backgrounder.
[2]. C. Y. Chang and S. M. Sze (Ed.), : "Nonvolatile Memory". (Chapter 8), *ULSI Devices* , John Wiley & Sons, Inc.,
[3]. Philofsky, E.M**,** FRAM-the ultimate memory. Sixth Biennial IEEE International Nonvolatile Memory Technology Conference, 1996., Page(s): 99 –104.