Total Ionizing Dose Effects in Ferroelectric Nonvolatile RAMs FM18L08.

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Abstract - Total Ionizing Dose (TID) experimental results for Ferroelectric Random Access Memories are presented. The purpose of the investigation was to experimentally determine whether peripheral circuitry or memory cells are most irradiation sensitive. Also, the fault coverage of testing algorithms with different operation counts (4N, 5N, 10N) was obtained.

Index terms – Ferroelectric Random Access Memory (FRAM), Total Ionizing Dose, testing algorithms.

I. Introduction

A problem of rad-hard systems development for space applications is urgent and can be solved by the implementation of the radiation hardened electronic devices especially nonvolatile memories. Ferromagnetic Random Access Memory is a type of a nonvolatile memory which is based on a thin-film ferroelectric (FE) technology. FRAM in comparison to other types of nonvolatile memories such as FLASH or EEPROM is more attractive in many ways: high speed, low supply voltage, high endurance, random access, write time, etc.

As known [1-2] PZT ferroelectric films are TID resistant up to 10 Mrad(Si). However, several reports [3-5] revealed that radiation hardness of FRAM chips did not exceed tens or hundreds of krad(Si). In paper [5] it was supposed that this rather low TID radiation hardness caused by weak periphery of FRAM chips.

The purpose of this paper is to estimate TID radiation hardness of FRAM chips and to experimentally determine whether peripheral circuitries (row and column decoders, sense amplifiers, etc.) or memory cells are most sensitive.

II. Devices Under Test

Throughout this work, commercial Ramtron FRAM chips FM18L08, featuring 32 k x 8 bits, operating at different supply voltage ranging from 3.0 V to 3.6 V, and with PDIP package were irradiated.

The irradiation was performed at the Specialized Electronic Systems (SPELS) and NRNU "MEPHI", using X-ray source REIM-2 with 10 keV mean photon energy and 50 keV maximum energy and linear electron accelerator U-31/33 working in bremsstrahlung X-ray radiation mode with 500 keV mean energy and 2,3 MeV maximum energy.

Before irradiation all devices were chemically etched to expose the die, and to avoid the X-Ray attenuation due to the packaging materials.

III. Experimental Technique

The experiment was divided in two parts. At first, several samples were irradiated at the electron accelerator and X-ray source in order to determine the level of radiation hardness and calibration. Testing by both facilities gave similar results and it allowed irradiating other samples only on X-ray source. At second, special irradiation according to [5] was performed. Chips were exposed to X-ray through the 2-mm shield with a 1.5-mm circular hole.

The functional control of all chips was performed by applying testing algorithms with different operation counts (N-the number of cells in memory): 10N - MARCH C-, 5N - MATS+ and 4N – Checkerboard and Zero-One. Traditional tests such as Checkerboard or Zero-One allow to detect only stuck at faults and some address decoder faults, at the same time patterns with operation counts more than 5N allow to detect all address decoder faults also [6].

Based on visual analysis of dies structure the location of CMOS peripheral structures was suggested. Accordingly three areas (pictured on the Fig. 1 areas 1, 2, 3) were irradiated applying shield. It was supposed that area 1 includes memory area with FE films and polysilicon and metallic lines, areas 2 and 3 include memory areas with FE films and CMOS circuitries.

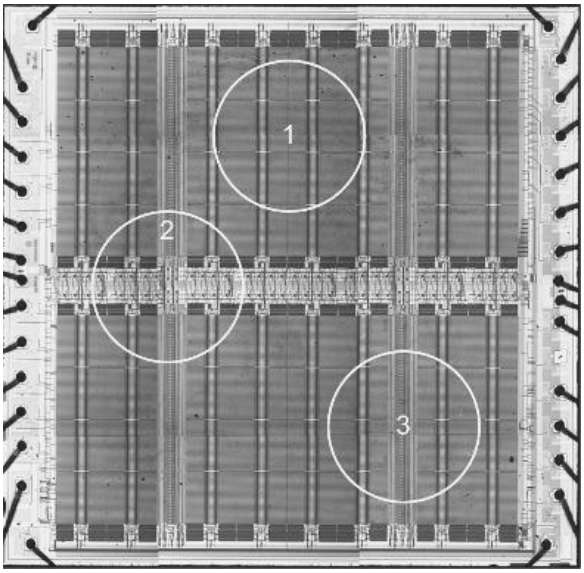

Fig.1. Areas on the dies FM18L08, which were irradiated through the shield.

A memory-pattern (0xAA) was written to FRAM-chips before irradiation. Irradiation was periodically stopped to perform operational and functional control while keeping memory map

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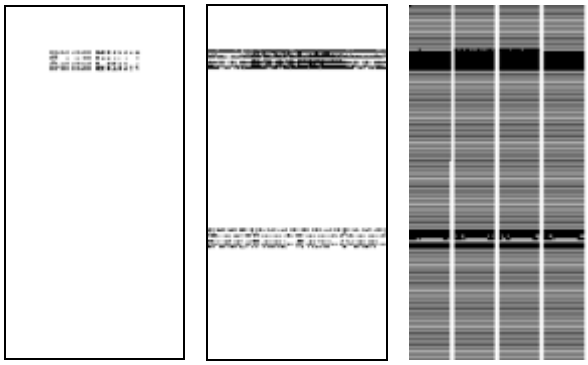
organized and considering the physical organization of chips.

IV. Results and Discussion

It was determined that FRAM FM18L08 maintains the complete functionality up to 16 krad(Si) when testing algorithms MARCH C- and MATS+ were applied and up to 30 krad(Si) when testing algorithms with operation counts 4N were applied. Herewith error bits were mostly arranged along rows and columns.

The samples irradiated with shield exhibited different TID radiation hardness depending on the place of the hole in the shield under die:

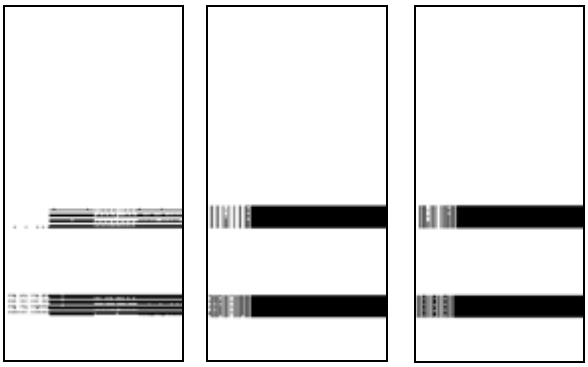
- Area 1: memories maintained the complete functionality for TID levels over 500 krad(Si).
- Area 2: memories maintained complete functionality up to 70 krad(Si) when testing algorithms MARCH C- and MATS+ were applied and up to 80 krad(Si) when testing algorithms with operation counts 4N were applied. Figure 2 shows that up to 110 krad(Si) errors were observed only in localized regions, after 120 krad(Si) errors appeared all over memory chip. Such result proves existence of row and column decoders in the area 2 which degradation leads to chip functionality loss.



(a) (b) (c)

Fig. 2. Physical positions of the failing bits (black points) in FRAM FM18L08 irradiated through the shield with a hole at area 2: (a) 90 krad(Si), (b) 110 krad(Si), (c) 120 krad(Si).

- Area 3: memories maintained the complete functionality up to 80 krad(Si), after 90 krad(Si) errors were observed when testing algorithms with operation counts both 4N and 5N, 10N were applied. Figure 3 shows that up to 500 krad(Si) errors were observed only in localized regions and the number of failing addresses did not increase up to 270 krad(Si). We can assume that in the area 3 only memory cells and sense amplifiers were irradiated, which degradation leads to failures only in irradiated region and rows which parts were included in this region. Fig. 4 shows evolution of number of failure addresses in FRAM-chips during irradiation through the shield with a hole placed in area 2 and 3.



(a) (b) (c)

Fig. 3. Physical positions of the failing bits (black points) in FRAM FM18L08 irradiated through the shield with a hole at area 3: (a) 250 krad(Si), (b) 270 krad(Si), (c) 500 krad(Si).

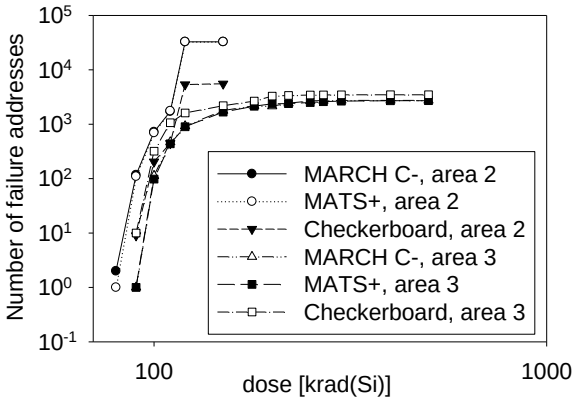


Fig. 4. Number of failure addresses in FRAM vs total dose.

V. Conclusion

As a result it was found that FRAM FM18L08 maintains the complete functionality up to 16 krad(Si). Testing on X-ray source and linear electron accelerator gave similar results.

Application of testing algorithms of different operation counts under functional control confirmed fault coverage and effectiveness of March Test Algorithms for TID experiment. In cases when chip functionality loss was associated with degradation of peripheral circuitries, March Test Algorithms allowed to indicate errors at lower total dose level compared to testing algorithms with operation counts 4N.

It can be assumed that FRAM FM18L08 to TID radiation hardness level derives from the accelerated degradation of the peripheral CMOS circuitries. Estimated levels of radiation hardness for different blocks of memory are the following: for sense amplifiers it is 70 krad(Si), for row and column decoders it is 80 krad(Si) and for memory cells, which consist of 1 transistor and 1 capacitor, which employs a PZT ferroelectric film, it is not less than 500 krad(Si).

VI. References

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