Weebitnano
THE NEXT NVM IS HERE

Whitepaper:

Design Considerations for Embedded NVM in High-Radiation Applications

March 2023

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Introduction

Nearly every electronic device in the world today uses non-volatile memory (NVM). Digital products that wake up, run code, sense the environment, process data and store data need NVM. Within these devices, NVM is used to store and load the operating system, program files, pictures/videos and data, as well as for configuration and trimming functions. In environments with high levels of radiation such as aerospace and medical devices, selecting the right NVM can be a key consideration since radiation can impact the operation of certain technologies.

Flash Memory and Radiation

While the types and levels of radiation that might affect NVM depend on the specific application, environment and duration of exposure, various levels of radiation can be a cause for concern when using flash memory.

Embedded floating gate memories such as flash store data as an electrical charge, making them particularly sensitive to even relatively low radiation doses. This is due to the direct interaction of ionizing radiation with their stored charge. The potential impacts of radiation on flash memory can be based on cumulative radiation exposure over time, displacement damage or potential single event effects (SEEs). The damage can vary, from flipping states, to permanently altering the atomic structure of the material. Research shows that this problem only increases with the move to smaller process geometries [1].

Given this sensitivity, using flash memory for applications in high-radiation environments adds complexity to the design process. Today, designers must add error correction code (ECC) to their designs and also add redundancy to enable continued operation in case of any failures. This increases the overall die size of a design, adds cost and increases latency [2].

Today, flash is the most commonly used NVM in electronic products, and until recently, there hasn’t been an alternative solution. With new NVM technologies entering the market however, designers now have a choice.

Radiation Tolerant NVM Technology

New memory technologies are now in the market that overcome many of the challenges associated with flash memory, including its sensitivity to radiation. Emerging memory technologies like Resistive Random Access Memory (ReRAM or RRAM), Phase Change Memory (PCM), Magneto Resistive RAM (MRAM), and Ferroelectric RAM (FRAM) offer alternatives to floating gate memory devices and can also scale more easily to advanced geometries.

Among these technologies, ReRAM is emerging as a leading candidate to replace flash memory for a broad range of applications. ReRAM technology is known to be insensitive to ionizing radiation, SEE damage and displacement damage, since there is no direct interaction between radiation and the storage mechanism of the technology [1, 3].

Weebit ReRAM in High Radiation Environments

Weebit Nano and the Nino Research Group (NRG) in the University of Florida’s Department of Materials Science and Engineering are studying the effects of radiation on Weebit ReRAM technology under various conditions. Results of initial studies confirm that Weebit ReRAM arrays are tolerant to high levels of radiation, able to retain data integrity and memory functionality after being subjected to high doses of gamma irradiation.

Here we share the details of initial studies.

Weebit ReRAM Irradiation Study Goals & Methodology

In the first studies carried out on Weebit ReRAM arrays by Weebit and NRG, the groups tested the ReRAM arrays under Gamma irradiation at the University of Florida Training Reactor (UFTR). Gamma radiation was produced using a Cs-137 source with a radiation rate of 702 rad/min, and samples were held in a rotating chamber. Samples were stressed from 0.5 Mrad radiation dose and up to 10 Mrad of radiation dose, which is 10x the total-ionizing-dose for the most constrained Rad-Hard applications. Different sets of arrays were used for each dose. A reference sample which was not irradiated was also included in the experiment, confirming that time between the two measurements (before and after irradiation) does not impact the resistance distribution.

ReRAM samples consisted of 16kb 1Transistor-1Resistor (1T1R) arrays integrated in the back-end-of-line (BEOL) of a 130nm CMOS test vehicle. Each sample was previously cycled up to 1k cycles, and then partly programmed in a High Resistive State (HRS) and partly in a Low Resistive State (LRS). During the irradiation, no bias was applied on the memory cells. After irradiation, cell resistances were read out and reprogrammed to ensure both data retention and memory functionality after irradiation.

The test protocol of the 16kb 1T1R array is described in **Figure 1**. Since the array design and integration were not Rad-Hard compliant, the test protocol also included the measurements and irradiation of 16kb 1T-only arrays to de-correlate drift or failure coming from the CMOS circuitry and not from the memory itself.

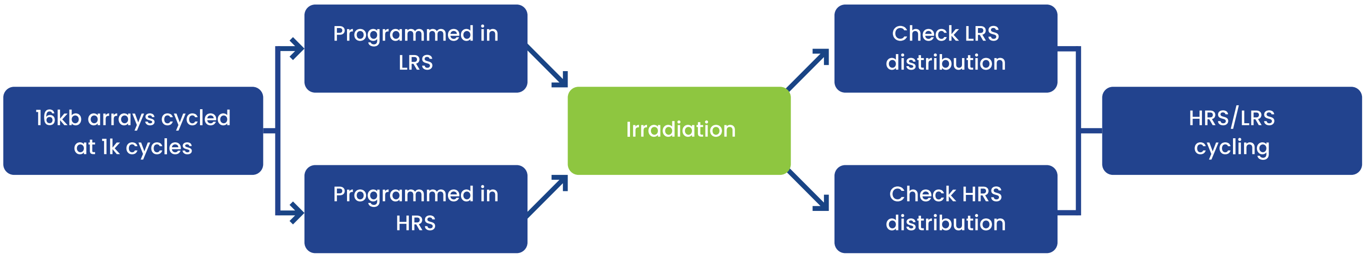

Figure 1: Diagram of the test protocol of 16kb 1T1R array

Weebit ReRAM Irradiation Study Results

Data retention after irradiation

LRS and HRS distributions are displayed respectively in Figure 2 and Figure 3 (note that figures are not at the same scale). For both the LRS and HRS states, no disturbances of the distribution were observed, even for the highest fluence of 10 Mrad. This confirms that ReRAM technology is able to sustain high radiation doses, up to 10 Mrad, without losing the information stored in the memory array.

Figure 2: Low Resistance State distribution before and after different radiation doses. Even at high dose, the LRS state is not disturbed (note that this is not the same scale as shown in Figure 3).

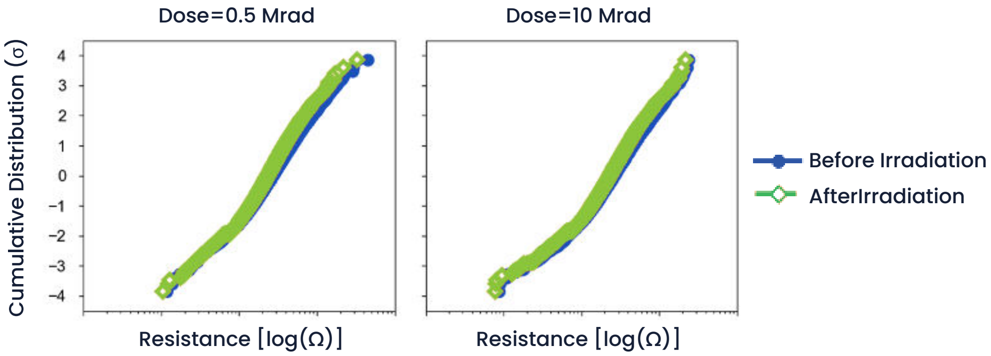

Figure 3: High Resistance State distribution before and after various radiation doses. Even at high dose, the HRS state is not disturbed (note that this is a different scale than shown in Figure 2).

Memory functionality after irradiation

Following the resistance measurement carried out after the irradiation, we performed a functionality test in which we reprogrammed the array to check if the memory performance and memory window were still optimum. In other words, to check the capability of the memory cell to be reprogrammed after being heavily irradiated. The same programming parameters were used as were used in the initial programming.

Since the programming can be disturbed by the degradation of the select transistor (and also the whole access circuitry) due to irradiation, it is essential to measure the transistor performances. Figure 4 presents the transistor drain current when the LRS programming condition was applied. We observe a slight decrease of the drain current after irradiation. Note that the curve is plotted in linear scale, meaning that it is a constant shift of the overall distribution. This is due to the high gamma irradiation dose that is known to degrade the performance of semiconductor devices. The reduction of the drain current implies a slight decrease of the LRS programming current as well as increasing the transistor resistance contribution during the reading operation, and thus, it is expected to shift LRS distribution toward higher resistance.

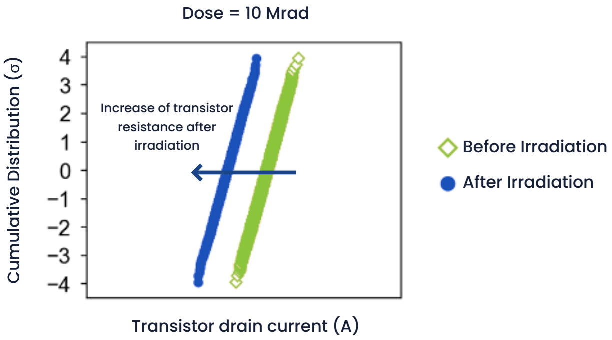

Figure 4: Distribution of select transistor drain current (using the same gate voltage) before and after irradiation at high dose. A shift of the distribution is observed, increasing the transistor resistance. Note that the curve is plotted in linear scale, meaning that it is a constant shift of the overall distribution.

LRS and HRS distributions measured after the reprogramming of the array are represented in Figure 5. As expected, a slight increase in the LRS distribution is observed, coming from the non-Rad-Hard design of the test vehicle used for this study (i.e., it comes from the increase of the transistor resistance rather than from a shift of the ReRAM performance). For the HRS state, the same distribution was observed after the reprogramming.

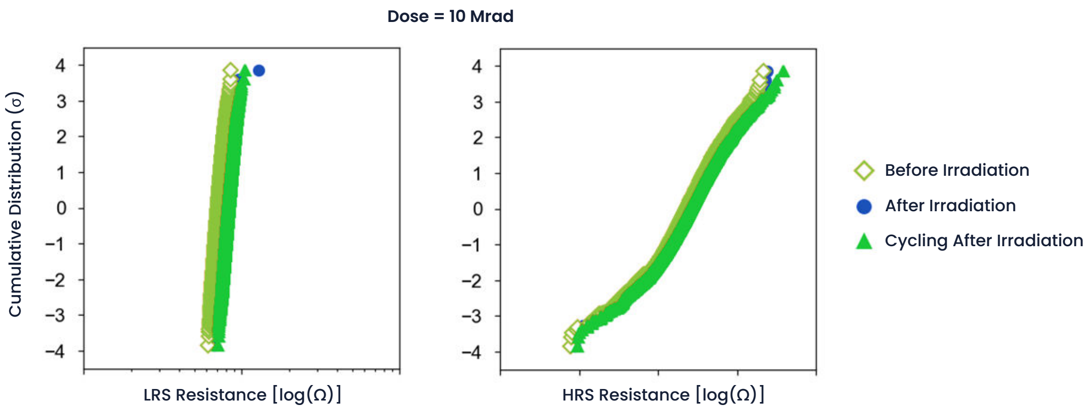

Figure 5: Memory functionality is ensured even after an irradiation at 10 Mrad. The slight increase of LRS state comes from the increase of the select transistor resistance and is not related to the memory performance.

In conclusion, both HRS and LRS distribution were preserved, confirming that after irradiation at high doses, Weebit ReRAM technology is able to preserve the information and can be fully reprogrammed.

Weebit ReRAM Irradiation Studies: Next Steps

In this preliminary study, only 16kb arrays were characterized. The next set of planned experiments will go further in both research and development directions. Irradiation experiments will include extending the type of radiation sources in order to cover the whole spectra of radiation environments that are encountered in medical and aerospace applications[4]. Weebit ReRAM modules will also be included in future runs of irradiation experiments, allowing an extensive characterization of Weebit technology for rad-hard applications. Then, the build-up of an in-situ test set-up at the University of Florida Training Reactor (UFTR) facility will allow a deeper understanding of the memory behavior when operating under radiation environments in real time.

Conclusions

Given the limits of flash memory in terms of speed, power, cost and endurance, as well as the economic and technical challenges of embedding flash memories into SoCs beyond 28nm for most applications, designers need NVM alternatives. This is especially true for SoCs in high-radiation applications, where embedding flash requires added complexity and redundancy.

Emerging NVMs like ReRAM are now entering the mainstream, offering radiation tolerant alternatives to flash. Our initial studies demonstrate that Weebit ReRAM is resilient to radiation. This, together with its scalability, higher endurance and access time, high reliability, lower power consumption and operating voltage, make Weebit ReRAM a compelling alternative.

These initial studies are just the starting point for investigations into the radiation tolerance of Weebit ReRAM. Future studies look at additional types of radiation in different doses and environments.

References

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Weebit Nano Ltd. is a leading developer of advanced semiconductor memory technology. The company's ground-breaking Resistive RAM (ReRAM or RRAM) addresses the growing need for significantly higher performance and lower power memory solutions in a range of new electronic products such as Internet of Things (IoT) devices, smartphones, robotics, autonomous vehicles, 5G communications and artificial intelligence. Weebit's ReRAM allows semiconductor memory elements to be significantly faster, less expensive, more reliable and more energy efficient than those using existing Flash memory solutions. As it is based on fab-friendly materials, the technology can be quickly and easily integrated with existing flows and processes, without the need for special equipment or large investments.

The Nino Research Group was established in 2003 by Prof. Juan C. Nino, professor of the department of materials science and engineering at the University of Florida. The group focuses on development of advanced functional materials for sustainable energy solutions and includes the investigation of electronics under extreme environments, neuromorphic neural networks, energy conversion and storage, and semiconductors and scintillators for radiation detection.

More Information

Weebit ReRAM/RRAM Technology Overview

Weebit ReRAM Technical Resources

Nino Research Group (NRG) in the University of Florida's Department of Materials Science and Engineering

To see a demonstration of Weebit ReRAM technology, contact us.

Learn how Weebit ReRAM can make all the difference for your design.

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