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THE FAST NEUTRON SEU CROSS SECTION OF A 4 Mb SRAM MEMORY

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ABSTRACT

The results of a static test of single event upset (SEU) produced by fast neutrons on an ISSI 4Mb SRAM memory are reported in this work. To perform the tests, it was built a platform based on a motherboard which is controlled by microprocessor, whose function is to perform the writing, reading and control of the memories under irradiation. The irradiation was performed with a set of 8 ^{241}Am-Be neutrons source in a quasi-isotropic incidence. The SEU cross was calculated from the accumulated bit flip count.

1. INTRODUCTION

The development of any project aimed to space and aeronautical applications must consider the undesirable effects of the continuous action of cosmic radiation in electronic components. The effects of this radiation must be known, in a way that corrective actions can be considered in the equipment design that must operate for long-time intervals immersed in an environment with permanent ionizing radiation [1].

Electronic instruments operating under ionizing radiation suffer adverse effects on its performance, resulting from the interaction of radiation with their basic components. In electronic circuits, these effects appear as transient or permanent deviations of electrical parameters of the circuit, malfunction or even complete failure of the system.

These effects can be classified as transient or cumulative, and may also be reversible or not reversible [2].

The transient effects are usually associated with rapid collection of electric charges released in a sensitive region of the device by the passage of a heavy ionizing particle, causing a spurious electrical pulse in the circuit node reached (Single Event Effects, or briefly, SEE). In digital circuits the most important SEE is the "bit flip" in logic cells, named Single Event Upset (SEU). For SEE tests, high energy particle accelerators are employed and thresholds

and cross sections for each type of SEE caused by protons and heavy ions are determined as a function of the linear energy transfer (LET) of these particles to the transistor material.

On the other hand, the ionization of the medium by neutrons is indirect, i.e., the ionization is caused by ions produced by neutron nuclear interactions with nuclei of the atoms of the medium. In the case of silicon, only fast neutrons can produce scattered ions with enough energy to generate the critical charge in the sensitive region causing a current pulse in circuit nodes. The neutron energy threshold depends on several factors, including the architecture and layout of the components in the cell, as well as the technology node. Neutron produced SEE cross sections are measured as a function of neutron fluence for each particular neutron energy spectrum. For aeronautical applications, the spectrum of neutrons generated by cosmic rays in the atmosphere is of great concern, whose energy extends up to 400 MeV. But, for nuclear applications, neutrons produced by radioactive sources, such as ^{252}Cf and ^{241}Am-Be, are the more representative of usual situations.

The results of a static test of SEU on an ISSI 4Mb SRAM memory of 130 nm technology (PN: IS62WV25616BLL) performed with the ^{241}Am-Be fast neutron spectrum are presented in this work.

2. EXPERIMENTAL PROCEDURE

The irradiation was performed with eight 100mCi ^{241}Am-Be neutron sources with $(7.87 \pm 0.24) \times 10^3$ n.cm^{-2}.s^{-1} neutron flux at DUT position. The dispositive under test (DUT) is positioned in a special configuration in order to simulate a quasi-isotropic neutron incidence, as show in Fig. 1. The memory chip (DUT) is irradiated from above and below by fast neutrons emitted by the sources. Between neutron sources and the DUT, there are two aluminum sheets, two lead sheets and one cadmium sheet, with 2 mm, 4.5 mm and 0.5 mm thicknesses each, respectively, above and below it. This setup was designed for shielding 59 keV gamma-rays from ^{241}Am and to eliminate thermal neutrons produced by scattering and thermalization in the polyethylene outer shields used for protecting the associated equipment. The thermal neutron capture gamma-radiation from cadmium was considered no significant because this memory is tolerant to TID demage. The neutron flux was obtained by Monte Carlo simulation using MCNP5 code.

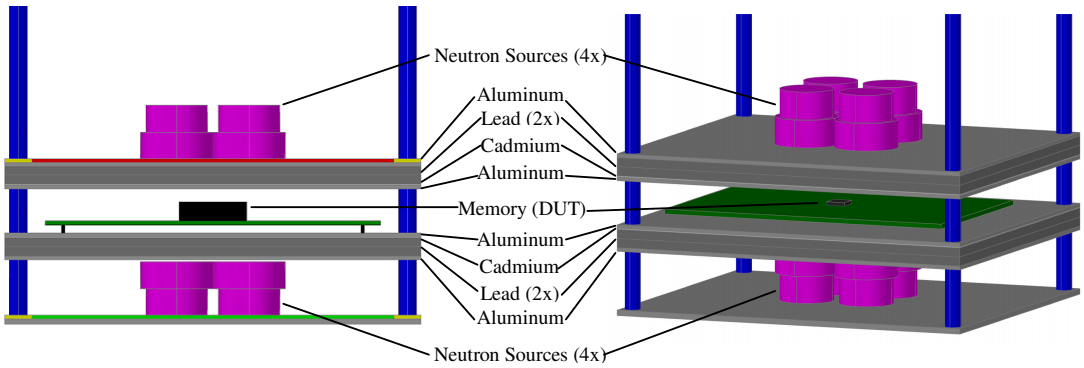

Figure 1: Irradiation setup

The fast neutrons produced by radioactive sources of ^{241}Am-Be are distributed in the energy range from 20 keV to 11 MeV and the neutron mean energy is 4.16 MeV [3].

To perform the measurements, it was built a platform based on a motherboard which is controlled by a microprocessor, whose function is to configure the test in order to perform the writing, reading and control of the memories under irradiation and, after each reading cycle, stores the data in a Log file. These memories are mounted on a daughter board which, in turn, is connected to the motherboard (Fig. 2). The data acquisition and storage is done through dedicated software running on an external computer linked to the motherboard via TCP/IP for the remote control of the experiment (Fig. 3).

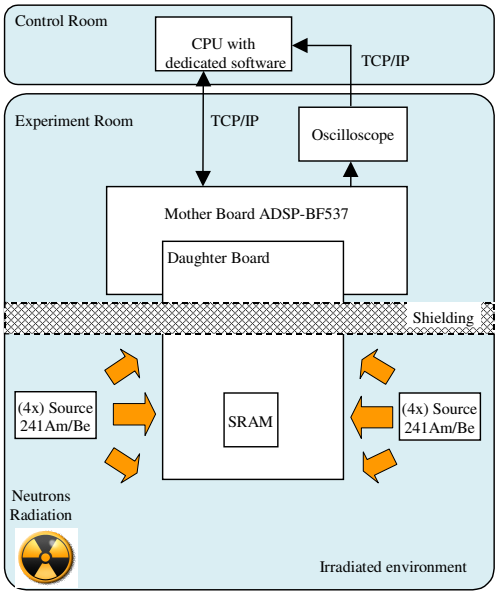

Figure 2: Block diagram of experimental arrangement

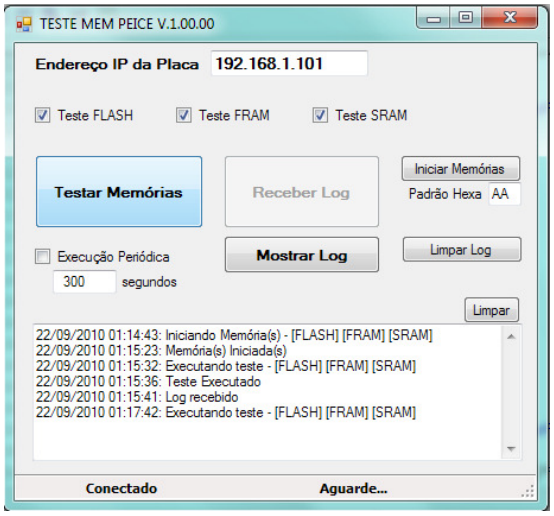

Figure 3: Screen of the dedicated software used in the experiment

This is a bit-memory oriented test, so it is convenient to write the same quantity of logical values 0 and 1 in the whole memories [4-6]. The test procedure is to perform a single write in the whole memory with a sequence of alternating bits whose value is AAAA in hexadecimal (1010101010101010 in binary) in the 16-bits word SRAM memory and, then, make periodic readings of the values stored during irradiation. At each reading cycle the addresses that showed any bit changes (bit flips) and its stored value are stored in a log file.

3. RESULTS AND DISCUSSION

Before the irradiation of the experimental setup, it was tested without radiation sources during 168 hours (one week) and no bit flip was observed, as it is expected.

The SRAM memory was irradiated continuously during 535039 seconds until the fluence of $(4.21 \pm 0.13) \times 10^{9}$ n/cm^2. It was detected 76 bit flip up (0 to 1) and 62 bit flip down (1 to 0), resulting in 138 bit flip for the entire memory (4MB). So, the SEU cross section is $(3.28 \pm 0.30) \times 10^{-8}$ cm^2 for the device or $(9.50 \pm 0.86) \times 10^{-15}$ cm^2/bit. This value is more accurate than our previous measurement reported elsewhere [7] whose value was $(4.4 \pm 1.5) \times 10^{-8}$ cm^2 for the same device type. The accumulated bit flip count grows linearly with the time of irradiation or fluence as show in Fig. 4. Due to the low statistics, it is not possible to conclude that there is any difference between the occurrences of bit flip up and bit flip down.

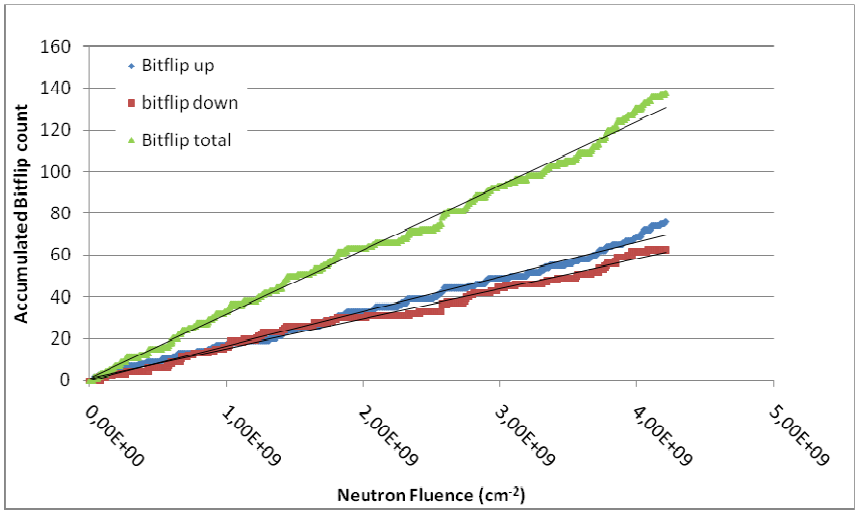

Figure 4: Growing the accumulated bit flip count during irradiation

In Figure 5 we show the frequency distribution of total bit flip per block of 16k-memory addresses, corresponding to a gross logical mapping of SRAM memory with respect to sensitivity to accumulated dose.

The low statistics of the experiment cannot conclusively show a homogeneous random distribution of bit flip in memory logical mapping, but there's no reason to say the contrary.

The mean value is 8.6 bit flip per block and a standard deviation of 3.2 bit flip per block. All bit flip counts per block remains within the interval of ± 2 standard deviation. Then, it is not possible to infer that there is some difference in SEU sensitivity for different regions of logical address in the memory.

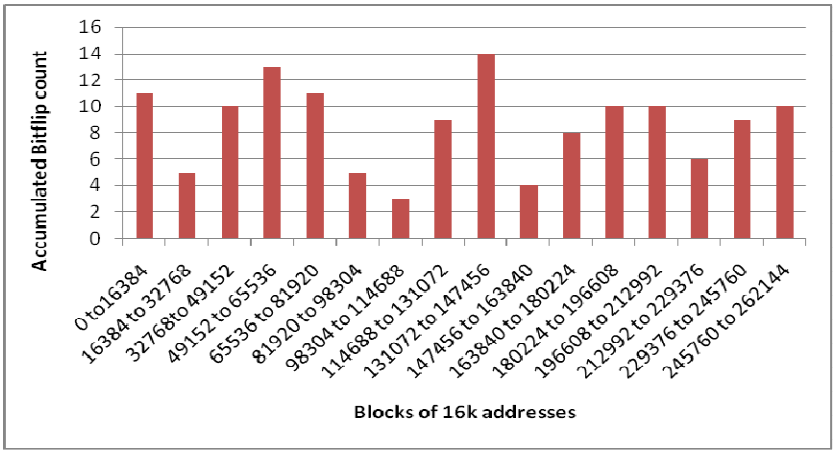

Figure 5: Bit flip frequency per block of 16k addresses for SRAM memory at 4.21×10^9 n.cm^{-2} fast neutron fluency

4. CONCLUSIONS

The results of this work shows that a 130 nm MOS memory is subject to change one logical record (bit flip) by the incidence of fast neutrons with energy less than 11 MeV, indicating that the threshold of the cross-section for SEU is, therefore, below this value. However, international normative documents applied to aviation [8-12], consider only the effects of neutrons above 10 MeV for the calculation of SEE occurrence rates in high altitude flights. The spectrum of neutrons generated by cosmic radiation in atmosphere extends up to energies of approximately 400 MeV, but presents an intense peak of evaporation neutrons around 1 MeV [13]. Since this type of memory is quite usual in many devices, and may be in avionics, this parameterization should be revised. Modern technology of micro-circuits fabrication have had an increasing degree of miniaturization, which in turn implies smaller threshold energy of radiation capable of producing single event effects (SEE) in general, including neutrons.

In this experiment there was no multiple bit flip in 16-bit words, which is an indicative of the low probability of MBU (Multiple Bit Upset) for neutrons with energy below 11 MeV. Also, all bit flip detected in this experiment were not permanent, because there was no write problems, so, no permanent damage was observed.

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