

SRAM-BASED PASSIVE DOSIMETER FOR HIGH-ENERGY ACCELERATOR ENVIRONMENTS

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Abstract

This paper reports on a novel Non-Volatile Random Access Memory (NVRAM)-based neutron dose equivalent monitor (REM counter). The principle of this device is based on the radiation effect initiating the Single Event Upsets (SEUs) in high density memories. Several batches of NVRAMs from different manufactures were examined in various radiation environments, i.e. $^{241}\text{Am-Be}$ (α , n) and Linear accelerator, produced radiation fields. A suitable neutron moderator was used to enhance the detector's sensitivity. Further experiments were carried out in a linear accelerator VUV-FEL. A separate batch of SRAM was irradiated with ^{60}Co -gamma source risen up to a dose of about 1.1 kGy. The proposed detector could be ideal for a neutron dose measurement produced by a high-energy electron linac, including synchrotron and Free Electron Laser (FEL) facilities.

INTRODUCTION

During the operation of high energy linear accelerators bremsstrahlung gamma and photoneutrons are produced [1]. Both gamma and neutrons pose a real threat to electronic devices installed in an accelerator tunnel. Therefore radiation measurement plays a crucial role to assure the reliable operation of accelerators. A large number of gamma detectors is currently available [2]. One can use photomultipliers, ionization chambers, scintillation counters and semiconductor-based dosimeters. Conversely to gamma, neutrons are uncharged particles, that have only a few interactions with matter, thus their detection is much more complicated than gamma. Neutrons are only detectable through measurements of secondary particles or a secondary phenomena [2, 3]. Superheated emulsion (bubble) and thermoluminescent (TLD) dosimeters can be used for sensitive neutrons measurement. Superheated emulsion dosimeters have a flat-response characteristic, however require an arduous bubble-counting process. TLD must be calibrated before the measurement.

The pulsed generation of neutrons in the high gamma background is difficult to measure. Gamma radiation has always an influence on the measured neutron fluence [2]. Only bubble dosimeters are able to measure neutrons fluence without gamma interaction.

Radiation present in linear accelerators, like the VUV-FEL or Linac II located at DESY, is produced because of the unwanted collision of the electronbeam with high Z materials in the beam line [1]. The amount of gamma is a few orders of magnitude higher than the neutrons' dose.

PRINCIPLE OF NEUTRON DETECTION

The basic idea of the SRAM-based dosimeter is to count the number of SEU induced in the memory during the measurement. SEU can be generated only by charged particles, which have relatively high Linear Energy Transfer (LET). Neutrons can be only detected from the secondary charged particles generated in the material (e.g. α , protons) [7].

The presented passive dosimeter uses Non-Volatile Random Access Memory instead of the classical SRAM device as a dosimeter, which is depicted in Fig. 1. SRAM devices

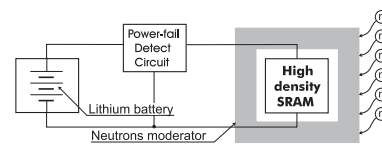


Figure 1: NVRAM-based neutron detector

cooperate with a lithium battery that provides a supply voltage when the memory is disconnected from the main power. An additional power supervisory circuit was implemented to detect a sudden disconnection from the main supply voltage and reconnect a back-up battery to avoid the accidental memory data corruption.

SEU in SRAM are generated by thermal neutrons which generate alpha particles present in accelerators, [5, 7]. Alpha particles have very high LET [7]. The energy is deposited along the ionising particle track, therefore electron-hole pairs are created. SEU is generated in the SRAM chip when a critical charge is deposited near the drain electrode of the MOS transistor [2]. The standard SRAM cell, presented in Fig. 2, consists of six MOS transistors, however only four are used to store a binary value. Solely, disabled transistors T_2 and T_3 are sensitive to SEU effect.

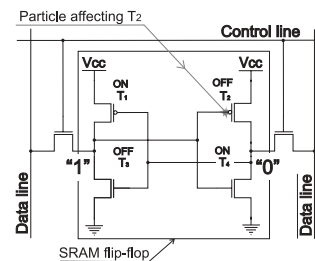


Figure 2: A single SRAM cell affected by ionising particle

The number of SEU induced in SRAM chips is proportional to the neutron fluence [3, 5]. However, the applica-

tion of SRAM as neutrons dosimeter requires a high sensitivity and linear response for a wide spectrum of detected particles. An appropriate neutron moderator assure a flat characteristics response for a wide spectrum of neutrons and allows to increase the detector sensitivity, see Fig. 1.

Design of Appropriate Moderator

All common neutron sensors (detectors), including SRAMs exhibits a high sensitivity to thermal neutrons. However, in all practical situations neutrons are not thermal but of much higher energy. The moderator is an entity which reduces the energy of the impinging neutrons to lower energies (process called thermalisation).

During the moderation process a part of the neutrons is also absorbed in the moderator. Therefore, a larger moderator reduces the neutron energy and absorbs a certain part of it, acting as a neutron shield. The experiments carried out in DESY Research Center in Hamburg proved that the sensitivity of the detector can be improved by the usage of higher density memories. The results of the experiment are presented in the following section. Memories designed for the operation with lower voltages (e.g. 3,3 V) are more susceptible to SEU. Moreover, SEU were detected in high density memories working on the ground level. Therefore, Error Correction Codes are implemented in modern high-density memories to avoid unwanted SEU in electronics. These type of SRAM chips are not good candidates for a neutron detector because of a very poor sensitivity to neutron generated SEUs.

A DEDICATED NVRAM READER

The contents of the NVRAM device can be read and written with a dedicated programmer. Configuration and reference data must be written to the memory before the first usage. This process is called memory formatting. The reference data can be programmed with a desired pattern. The application of a few different patterns allows to choose the most sensitive one. This pattern should be used for future measurements.

The configuration data are written to the memory starting from the address 0 up to 0x3FF. The data written with a repeated redundancy describe: memory density, its configuration, pattern used for the measurement, calibration factor, memory signature, date and the accumulated dose from the first usage. Some of these data are obligatory to calculate the neutron fluence during the irradiation (e.g. memory density, calibration factor), other can be used for diagnostic purposes. SEU generated in both main and configuration memories can be as well used to calculate neutron fluence.

The schematic diagram of the reader is shown in on Fig. 3. Data read from the memory can be displayed on LCD or sent to a PC computer. The device is able to operate 3.3 V and 5 V chips. The calibration factor read from the configuration memory of the chip is used to calculate the absorbed dose after the measurement. Fig. 4 presents

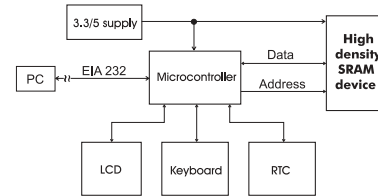


Figure 3: Schematic diagram of the SRAM reader

the Graphical User Interface (GUI) and some results for the measurement carried out in Linac II accelerator.

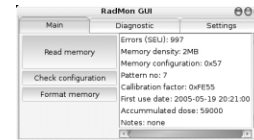


Figure 4: GUI interface of the dedicated NVRAM reader

RESULTS AND DISCUSSION

NVRAM chips fabricated by Texas Instruments and Dallas were used during the experiment. The devices were calibrated with a standard neutron source $^{241}\text{AmBe}$ during 24 hours. The source was moderated with the use of deionised water in order to imitate the energy spectrum of the linear accelerator [6]. Cross-sections for the memories, used during the experiment and Calibration Factors (CFs) are shown in Fig. 5. CFs allow to calculate neutrons fluences relying on induced in SRAMs SEUs.

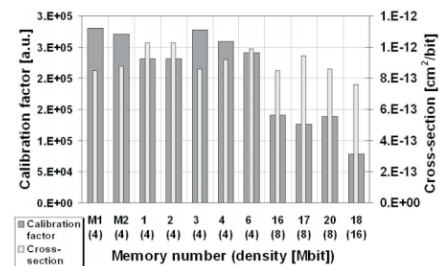


Figure 5: CFs and cross-sections for the memories irradiated from AmBe

Measurements in VUV-FEL

Previously investigated memories with additional bubble and TLD dosimeters were irradiated within 48 hours in the VUV-FEL accelerator. The devices with numbers 1 and 2 were placed 50 cm from the bunch compressor 2, the memories 3, M2, 6, 4, 17 were placed along the accelerating module 1, from input to output of the module. However chips 16, 18, 20, 21 were attached to the tunnel's

wall, opposite to the modules 4 and 5. The cross-sections and neutron fluences calculated for the memories are presented in Fig. 6. The memories 16 and 18 were covered

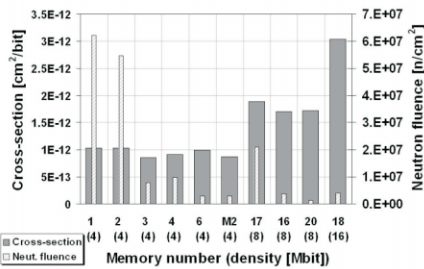


Figure 6: Cross-sections and fluences for the irradiated memories in VUV-FEL

in a polyethylene moderator, with the dimension equal to 6 cm, however chips 20, 21 were irradiated directly with no moderated neutrons. The results are presented in table 1. Neutron fluence calculated for the memory 20 is very

Table 1: Results obtained for 1 and 2 MB NVRAMs

No	Memory density [Mbit]	Induced SEU	Neutron fluence [n/cm ²]	Additional Moderator
20	8	10	1387522	no
21	16	21	1358192	no
16	8	26	—	yes
18	16	53	—	yes

close to the value obtained from the memory 21. The superheated emulsion dosimeter generated 44 bubbles. This result corresponds to 956 μ Sv. The dose of gamma radiation registered by TLD was equal to 3178 μ Sv. The devices were irradiated in VUV-FEL tunnel without the moderator. Memories 16 and 18 were packed in a polyethylene moderator. The number of SEU registered for these devices is two and a half times higher than SEUs generated, respectively, in memories 1 and 2. The lack of calibration factors for memories with moderators prevents the calculation neutron fluences.

High Gamma Dose Irradiation

Two batches of 256 kB memories were irradiated with a strong cobalt ⁶⁰Co gamma source, within 31 days. The dose of radiation absorbed by the memory was equal to 1.1 kGy. No SEU was registered in the memory contents. This validates, that gamma radiation has a negligible effect to trigger SEU in the SRAM.

SUMMARY AND CONCLUSIONS

High gamma background and pulsing neutron fields present in linear accelerators requires the usage of dedicated dosimeters to measure neutrons fluence. SRAM-based detector, insensitive to gamma radiation can be used as a neutron dosimeter. Experiments, carried out in VUV-FEL tunnel and with ²⁴¹AmBe proved that the sensitivity of

the detector can be increased more than ten times. Another method to improve sensitivity is to use selected memories as regards to density and supply voltage.

The application of repeated redundancy allows to keep all necessary parameters of the memories in SRAM cells, therefore decreases the reading time and simplifies its operation. There is no need to set the memory density before reading of the irradiated chip. The number of generated SEU in memories of the same density was different, therefore NVRAM devices require individual calibration.

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