Simplified Simulator for Neutron-Induced Soft Errors Based on Modified BGR Model

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Abstract

Recently the importance of cosmic ray neutron-induced soft errors has been recognized. We proposed a simple model for neutron-induced soft error rates, which is a modified version of the BGR model and developed a simulator, MBGR. MBGR can easily and quickly estimate neutron-induced soft error rates with high accuracy.

1. Introduction

Secondary cosmic rays, especially neutrons, can induce soft errors (SEs) in digital electronics via nuclear reactions with silicon (or other) nuclei at sea level [1]. It was shown that soft error rates (SERs) induced by α-particles from radioactive impurities in electronic materials are negligible and SERs are dominated by neutrons in memory circuits [2]-[5] and in logic circuits [6]-[9]

Previously, we proposed a Neutron-Induced Soft Error Simulator (NISES) and applied it to SEs in logic circuits to demonstrate its ability [7]-[9]. In this report, we propose a more simplified simulator, MBGR, for neutron-induced SEs based on the modified Burst Generation Rate (BGR) model.

The BGR model was initially proposed by Ziegler [1] and a simplified version was introduced by Normand [10]. Normand's BGR function is defined for an infinite volume in a Si medium and is only dependent on the collected charge. However, we carried out neutron-induced charge collection measurements for SOI diodes of various SOI thicknesses and have shown that the BGR function is dependent on the SOI thickness [11]. In this paper, we redefined the BGR function with a sensitive depth as a parameter and proposed a modified BGR model and developed a simulator, MBGR. MBGR can easily and quickly estimate neutron-induced SERs with high accuracy.

2. Modified BGR Model

Following Normand's BGR model, the neutron-induced SER is given by

$$\mathrm{SER}(Q_c) = \mathrm{BGR}(Q_c) \cdot \mathrm{N} \cdot \mathrm{Vs} \cdot \mathrm{C}, \qquad (1)$$

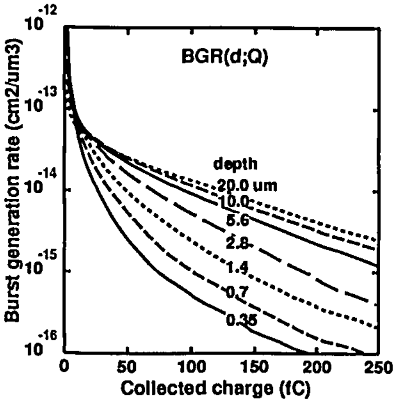

Figure 1: Sensitive depth dependence of BGR function.

where BGR is the burst generation rate, N is the neutron flux, Vs is the sensitive volume, C is the correction factor, and Q_c is the critical charge of the SE. The meaning of the burst generation rate is the rate of the neutron-nuclear reaction which occurred in a unite volume for an incident neutron. It is assumed that the bursts induced in the sensitive volume contribute to SEs. However, this model includes some ambiguities. For example, the correction factor C is alway less than 1, and the value of C should be determined with some experimental results. However, using a model without the extra parameter is more desirable. Furthermore, the original BGR function is defined for an infinite volume, but we found that the BGR function depends on the sensitive depth as suggested in a previous work [11].

Figure 1 shows the sensitive depth (d) dependence of the BGR function as a function of the collected charge (Q) calculated with our simulator NISES. For this simulation, an atmospheric neutron spectrum was assumed and the contributions from all neutron-induced reaction products were calculated. For large d, the BGR function approaches a universal line. However, the BGR rapidly decreases as d decreases. Therefore, we redefined the BGR function as BGR(d;Q) and the SER as

$$\mathrm{SER}(Q_c) = \mathrm{BGR}(d; Q_c) \cdot \mathrm{N} \cdot \mathrm{Vs}. \qquad (2)$$

We made database of BGR(d;Q) for an atmospheric neutron spectrum using NISES and developed a simulator, MBGR.

In MBGR, the parameters Vs (S × d) and Qc in Eq. (2) are determined as follows. We choose a rectangular parallelepiped as the sensitive volume around an error sensitive junction, with S determined by the junction area plus the depletion area [7][8]. The sensitive depth d is determined using the funneling model [12]. The critical charge, Qc, is estimated as the node capacitance, C_{node}, times the supply voltage, V_{DD}. C_{node} is estimated as the total parasitic capacitance for the node in SRAM memories, CMOS SRAM, and Latch circuits, and is estimated to be half of the storage capacitance, C_{cell}, of DRAMs.

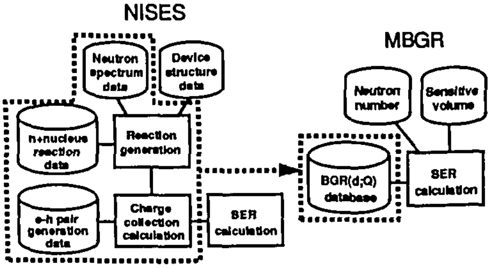

Figure 2: Outline of NISES and MBGR.

Table 1 NISES and MBGR

	NISES	MBGR
database	30 Mbyte	20 Kbyte
output data	10 Mbyte	1 Kbyte
simulation time (WS)	1 hour	1 sec

3. Ability of MBGR

At first, we explain NISES for the comparison (Fig. 2). The neutron spectrum and the device structure are the input data. NISES has both a neutron-nucleus reaction and an electron-hole pair generation database. Neutron-silicon reactions are randomly generated in the silicon substrate using the Monte Carlo procedure. If the reaction product passes through a sensitive junction area, the charges induced in the sensitive volume are calculated. It was assumed that if the collected charge passes a critical charge, an SE occurs. These processes are repeated about a million times and, finally, the SER is calculated. In MBGR, some parts in NISES are replaced by the BGR(d;Q) database and, therefore, the construction is largely simplified (Fig. 2). In NISES, memories of the database and the output data are 30 Mbyte and 10 Mbyte, and the SER simulation time is about an hour using the work station (SUN SPARC STATION 2). On the other hand, these values reduce to 20 Kbyte, 1 Kbyte and 1 sec, respectively, in MBGR (Table 1).

To verify the accuracy of MBGR, we applied MBGR to 0.35 μm CMOS circuits. Figure 3 shows the measured and simulated SERs as a function of the critical charge for CMOS SRAMs. The results of MBGR and NISES were shown. The experiment was performed at the Los Alamos National Laboratory using a pulsed neutron beam

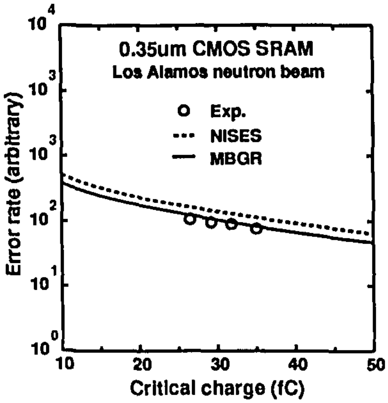

Figure 3: Neutron-induced SERs in CMOS SRAM.

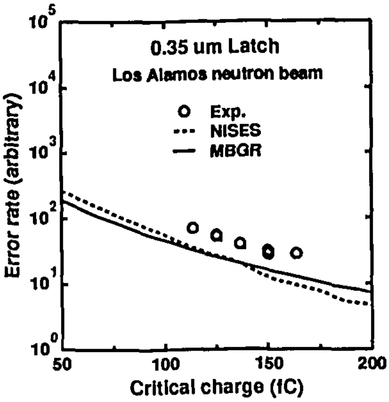

Figure 4: Neutron-induced SERs in Latch circuit.

which has an energy spectrum similar to the sea-level atmospheric neutron energy spectrum [4][9]. The SERs of MBGR agreed with those of NISES within a factor of 2. Accidentally, SERs of MBGR agreed with measured SERs better than those of NISES. Figure 4 shows the measured and simulated SERs of Latch circuits. The SERs of MBGR agreed with those of NISES and reproduced the measured SERs within a factor of 3.

4. Conclusion

We proposed a simple model to estimate neutron-induced SERs, which is a modeified version of the BGR model, and developed a simulator, MBGR. We can easily and quickly estimate neutron-induced SERs using MBGR. MBGR reproduced NISES simulations and predicted measured SERs within a factor of 2 to 3.

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