III. 2. Effective Estimation of Neutron-Induced Soft Error Rate on Advanced DRAMs Beyond 100 nm

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Terrestrial neutron-induced soft-error or single event upset (SEU) in semiconductor devices is one of the most crucial reliability-issues in the cutting-edge memory devices, for example, deep-submicron static random access memories (SRAMs)¹⁻³. Designers of electronic systems such as high-end servers, therefore, need the soft-error rate (SER) data of the electronic components in order to architect the system reliability securely. We have intensively developed the SER estimation method for memory devices mainly using monoenergetic and quasi-monoenergetic neutron beams generated by accelerators, which is well reflected also in JEDEC Standard/JESD89A⁴ published in Dec. 2006. The essential concept of the method is summarized as follows: the inherent excitation function of a device \( \sigma(E) \) is described as the Weibull-type function¹⁻⁴,

\[
\sigma(E) = \sigma_\infty \left[ 1 - \exp \left( - \left( \frac{E - E_{th}}{W} \right)^S \right) \right],
\]

(1)

where \( \sigma_\infty \) is the saturated value of the SEU cross section, \( E_{th} \), the threshold neutron energy for SEU, W, the scale factor, and S, the shape factor of the Weibull function, respectively. The SER of the device is estimated in the unit of FIT (failure in time; a number of errors in \( 10^9 \) hours) by the formula

\[
\text{SER [FIT]} = 3.6 \times 10^{12} \int_{E_{th}}^{\infty} \sigma(E) \frac{\partial \phi_r(E)}{\partial E} \, dE,
\]

(2)

where \( \phi_r(E) \) means the flux of terrestrial neutrons at a specific place on the ground, for example, at sea level (0 m) in New York city.

Neutron irradiation experiments concerning DRAMs with stacked capacitors from
250-nm to 110-nm process were performed using monoenergetic and quasi-monoenergetic neutron beams of peak energy from 5 to 174 MeV at FNL (Fast Neutron Lab.) and CYRIC of Tohoku Univ. in Japan, and at TSL (The Svedberg Lab.) of Uppsala Univ. in Sweden. Typical neutron spectra, which were used in the experiments, are shown in Fig. 1. Neutron energy dependence of SEU cross sections of each device is acquired by using monoenergetic and quasi-monoenergetic neutron beams. Test result of, for example, 220 nm DRAM is shown as solid triangles in Fig. 2. After approximating the energy dependence of SEU cross sections to the Weibull-type function (solid line in Fig. 2), SER of each devices at sea level in New York City was estimated by the self-consistent SER evaluation system, SECIS, by which estimated SERs are consistent with the results of real-time SER (field test) of a SRAM within 35% in accuracy. The estimated SER of each device from monoenergetic and quasi-monoenergetic neutron irradiation tests is shown in Fig. 3. This figure shows that the SER of the DRAMs was effectively suppressed as its down-sizing to 150 nm owing to (i) the high storage capacitance, (ii) the shrinking of junction-volumes and (iii) the relatively gradual voltage scaling. The constant SER-trend beyond 150 nm process technology node could be attributed to the difficulty of the design of the stacked-capacitor-type DRAMs at high yield of manufacture because of the high aspect ratio of the capacitor structure. Figure 3 contains also the problem of carrying out irradiation tests. Because of the less susceptibility to neutron-induced soft-errors, it becomes harder to acquire a statistically enough number of error events within an allocated beam time using the neutron beams with a low flux ($\sim1\times10^5$ n/cm²/s). A high intensity neutron source with a neutron flux around $1.5\times10^6$ n/cm²/s installed in CYRIC is very useful for the soft-error testing of devices with relatively higher immunity, and makes it possible to estimate the SER of such devices effectively.

References


Figure 1. Typical energy spectra of monoenergetic and quasi-monoenergetic neutron sources. F denotes FNl, C, CYRIC and T, TSL.

Figure 2. The test and the fitting results for 220-nm DRAM.

Figure 3. The SER-trend of DRAM with stacked capacitor from 250 to 110 nm process technology node. The solid line is an eye-guide for the trend.