HARBIN INSTITUTE OF TECHNOLOGY

Reliability Analysis of Memories suffering MBUs for the Effect of Negative Bias Temperature Instability

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Shanshan Liu, Liyi Xiao, Xuebing Cao and Zhigang Mao

Microelectronic Center, Harbin Institute of Technology

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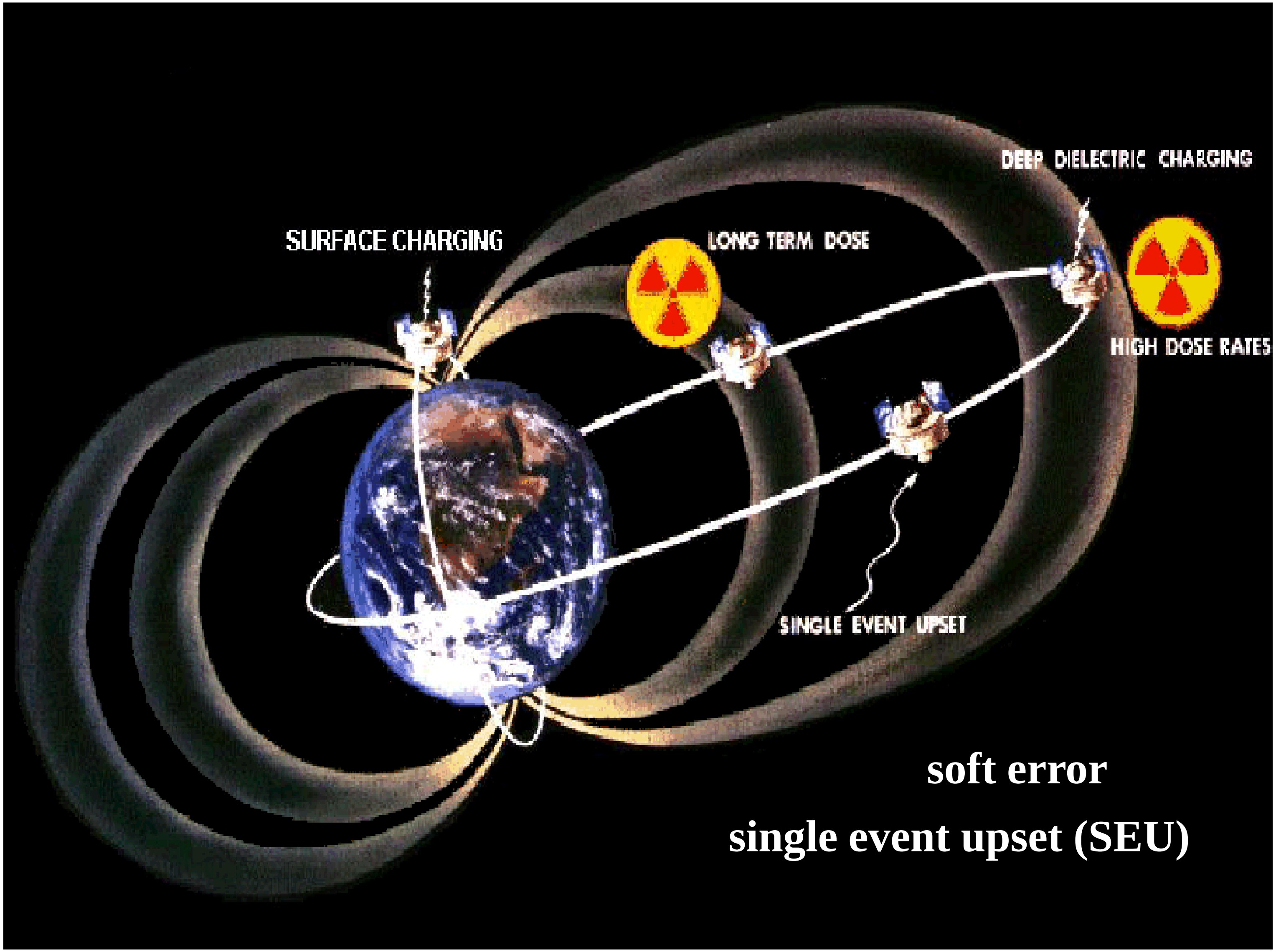
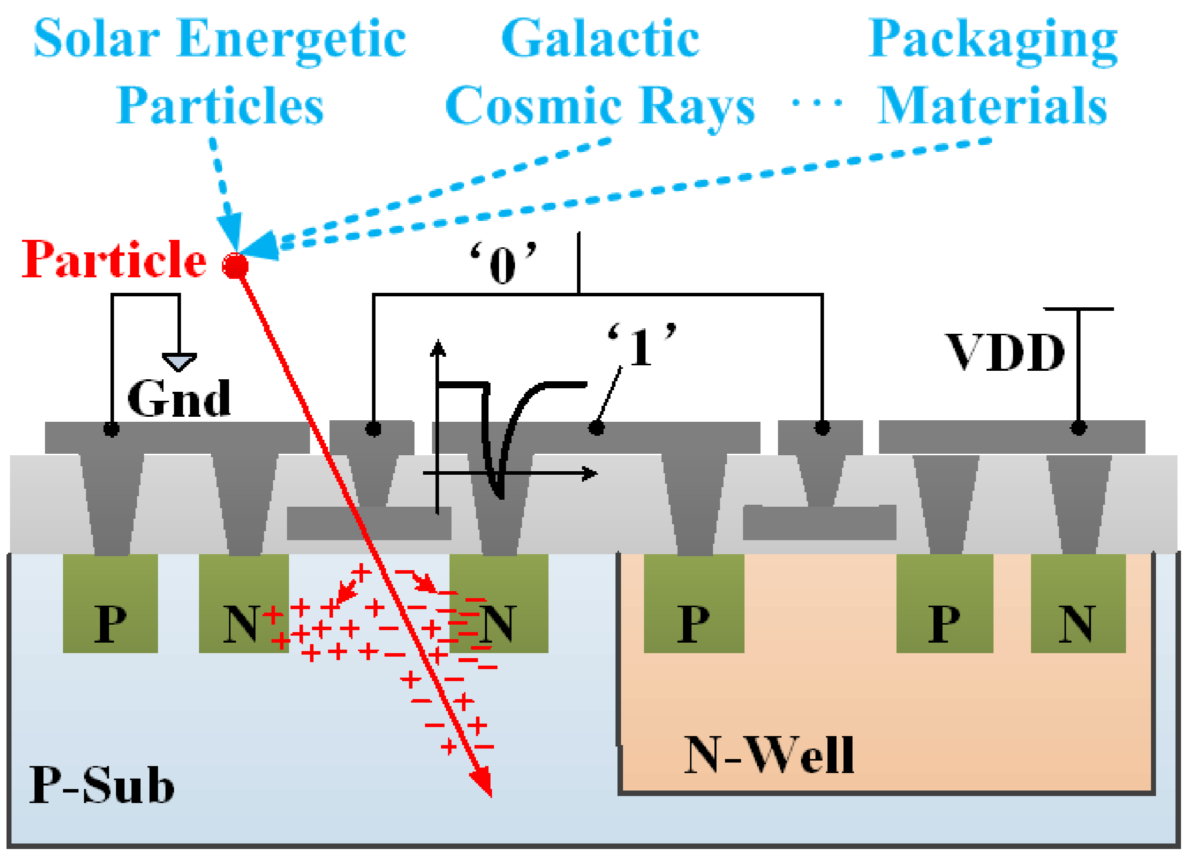
OUTLINE

- Background
  - SEU
  - NBTI
- The proposed reliability model for memories
  - Geant4 simulation
  - MTTF modeling
- Simulation results
- Conclusion

Radiation Environment



How does an SEU occur?



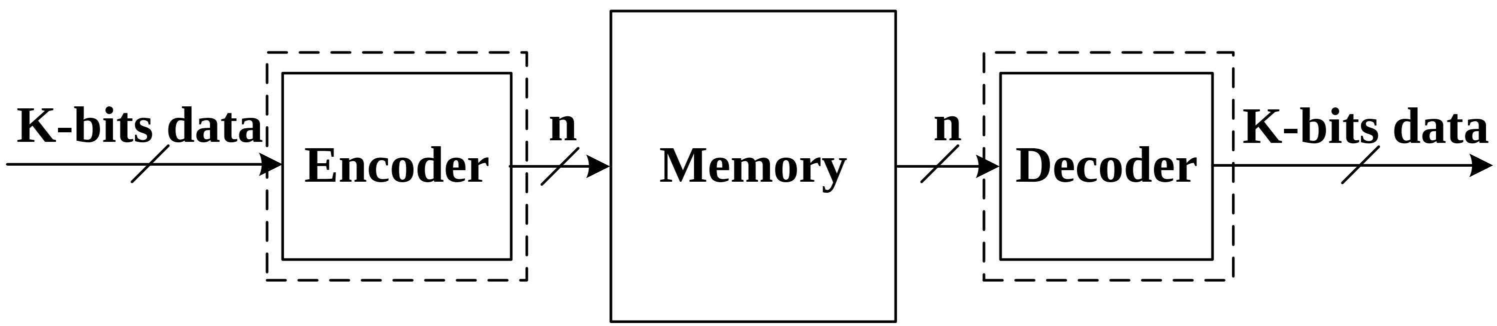
Long Term Service

Negative Bias Temperature Instability (NBTI)

- NBTI is one of the predominant aging effects.
- NBTI changes PMOS parameters over time due to oxide trapped charge and interface state generation.
- The absolute threshold voltage of PMOS can increase by more than 50mV over ten years. M.Agarwal,08

Error Correction Codes (ECCs)

- ECCs are commonly used to protect memories against MBUs.
- ECCs can be used by combining with scrubbing technique in case of high transient error rate.



Mean Time to Failure (MTTF) for Memories

- Some assumptions for MTTF modeling:
  - Soft errors arrive at memories following a Poisson distribution.
  - Memory cells are regular, thus soft errors are uniformly distributed across all cells.
  - If memories are protected by ECCs with *L* correct-capability, at least *L*+1 errors accumulated by two events in the same word are the dominant situation causing a failure.

MTTF

$$MTTF\,|_{MBU}^{nonscrubbing} \cong MTTF\,|_{SBU} = \frac{1}{\lambda}\cdot\sqrt{\frac{\pi\cdot M^{'}}{2}} = \frac{1}{\lambda^{'}}\cdot\sqrt{\frac{\pi\cdot M}{2}}$$

$$MTTF\,|_{MBU}^{scrubbing} \cong MTTF\,|_{SBU} = t_s\cdot\frac{2\cdot M}{\left(\lambda^{'}\cdot t_s\right)^2} = t_s\cdot\frac{2\cdot M^{'}}{\left(\lambda\cdot t_s\right)^2}$$

M. Zhu, 11

$$M^{'} = \frac{M}{P_f}$$

The level of MTTF will be **overestimated** without considering NBTI.

- *M* and *λ* are the memory size and event arrival rate under SBU, respectively.
- *M'* and *λ'* is the relevant memory size and event arrival rate under MBUs, respectively.
- t_s is the scrubbing interval.
- P_f is the total failure probability in a word caused by two events.

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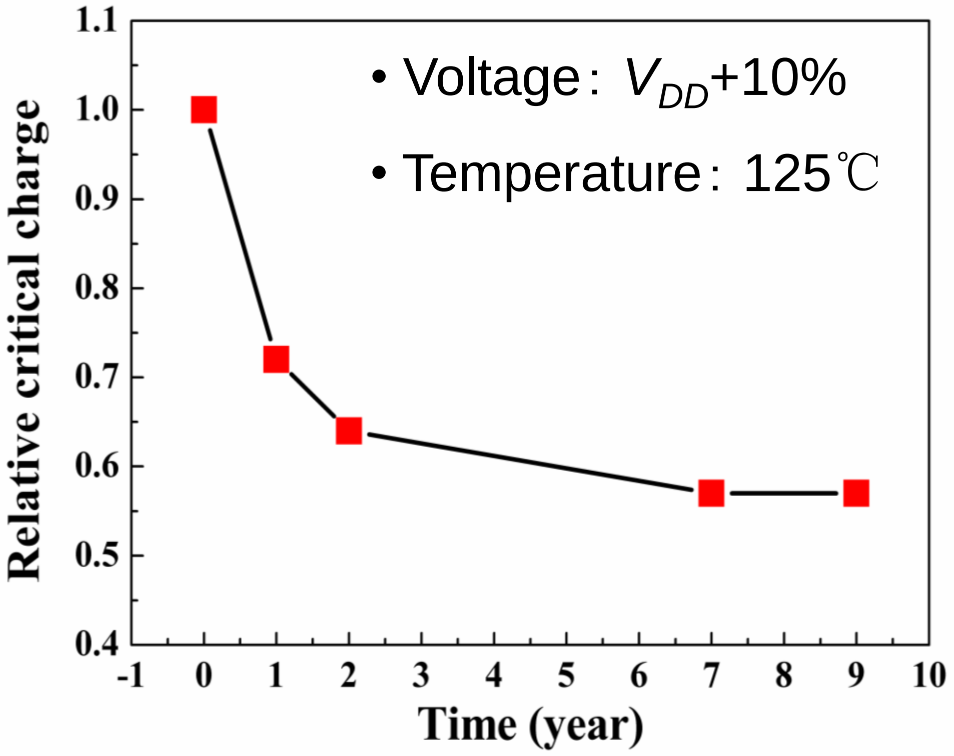
Impaction of NBTI on SEU Critical Charge

- **The SEU critical charge of a 65 nm technology SRAM is reduced under NBTI stress**



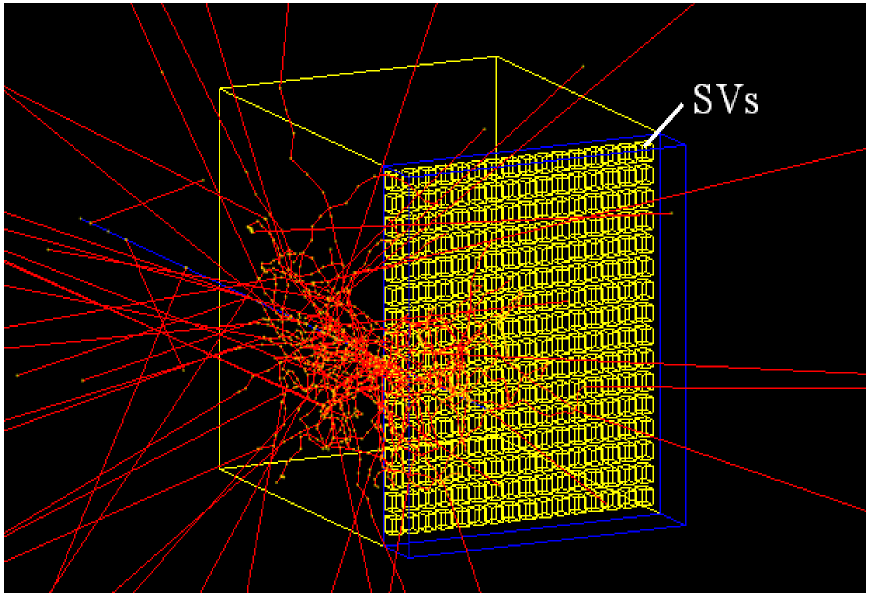
Relative SEU critical charge versus NBTI stress time.

I. E. Moukhtari 13

SRAM Array Hit by Heavy Ions

- Sensitive volume (SV): RPP D. E. Fulkerson 10
- SRAM array: 16 × 16 SVs
- Technology : 65 nm
- Ions: ^{20}Ne (2.8 MeV-cm^2/mg)

  ^{40}Ar (8.6 MeV-cm^2/mg)
- Incident angle: 0°, 45°, 79°
- Tool: Geant4



Cross Section

- According to the simulated SEU events, cross section can be obtained by:

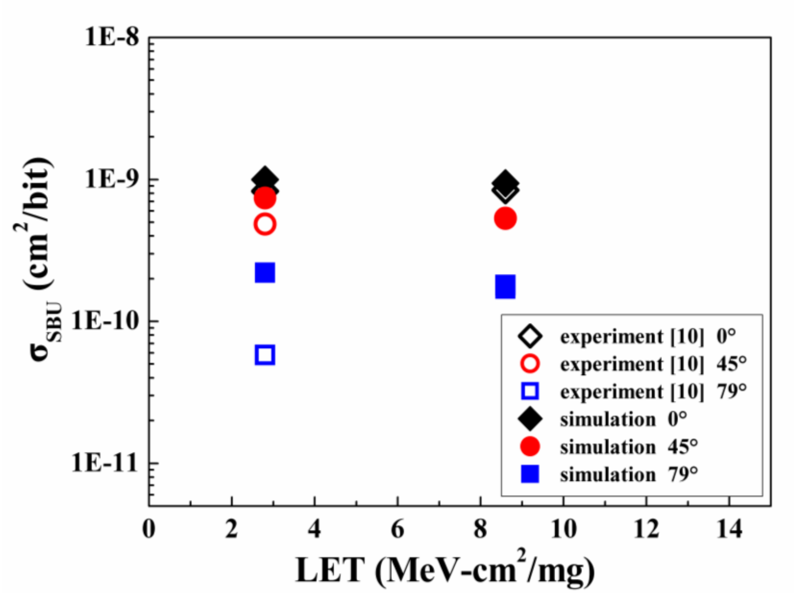
$$\sigma_{SBU} = \frac{Event_{1-bit}}{\Phi}$$

$$\sigma_{MBU} = \sum_{i=2}^{\infty} \frac{Event_{i-bit}}{\Phi} = \frac{Event_{2-bit} + Event_{3-bit} + Event_{4-bit} + \cdots}{\Phi}$$

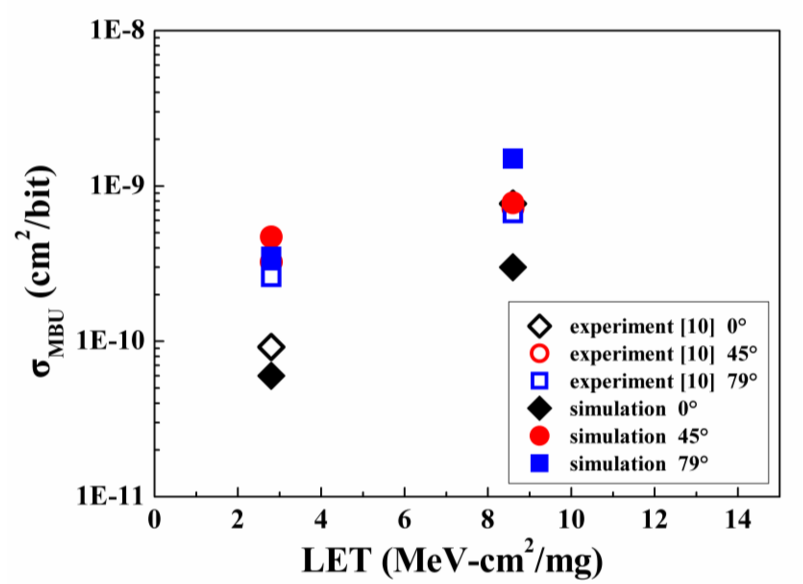
- Φ is the fluence.

Simulation

- Simulation results of σ_{SBU} and σ_{MBU} almost fit well with the experiment results. A. D. Tipton 08
- The few disagreement may be caused by the precision of SVs and other process information.



The single-bit upset cross section σ_{SBU} caused by two ions for experiment and simulation for both device orientations.



The single-bit upset cross section σ_{MBU}caused by two ions for experiment and simulation for both device orientations.

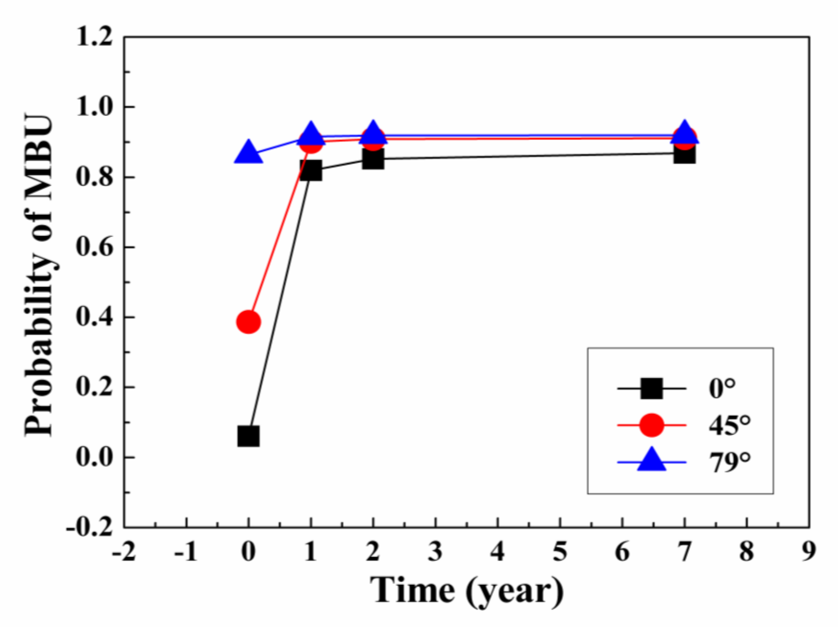
Probability of MBUs

- SEU events are simulated by setting different critical charges that are equivalent to different NBTI stress times, the probability of MBUs pMBU can be obtained by:

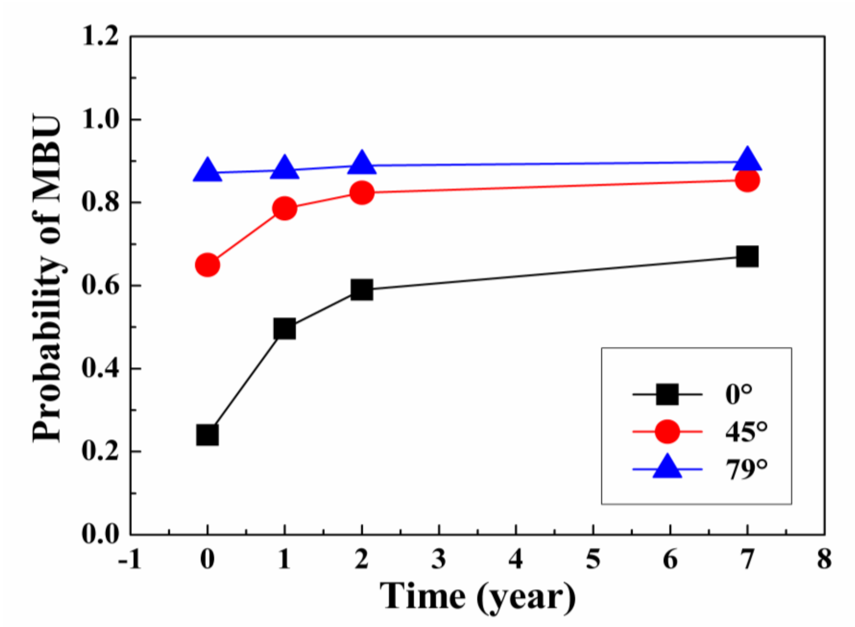
$$p_{MBU} = \frac{Event_{MBU}}{Event_{SBU} + Event_{MBU}}$$

Probability of MBUs

- The probability of MBUs increases when NBTI stress time accumulates, and the trend is approximately exponential.



The probability of MBU caused by ^{20}Ne (2.8 MeV-cm^2/mg) for three incident angles verse NBTI stress time.



The probability of MBU caused by ^{40}Ar (8.6 MeV-cm^2/mg) for three incident angles verse NBTI stress time.

Probability of MBUs

- Part 1: each incident angle
- Part 2: impaction of angles

$$p_l^1 = p_l \cdot \left(A_1 + B_1 \cdot e^{-\frac{t}{C_1}} \right)$$

$$p_l^{'} = p_l \cdot \left(1 + c \cdot \frac{\theta^\circ}{90^\circ} \right)$$ M. Zhu, 11

$$p_l^2 = p_l \cdot \left(1 + \frac{\theta^\circ}{10^\circ} \cdot \left(A_2 + B_2 \cdot e^{-\frac{t}{C_2}} \right) \right)$$

$$p_{l\_NBTI} = p_l \cdot \left(A_1 + B_1 \cdot e^{-\frac{t}{C_1}} \right) \cdot \left(1 + \frac{\theta^\circ}{10^\circ} \cdot \left(A_2 + B_2 \cdot e^{-\frac{t}{C_2}} \right) \right)$$

- p_{l_NBTI} is the probability of l-bit MBUs considering NBTI stress time t .
- A_1, B_1, C_1, A_2, B_2, C_2, are decided by the type and energy of particle.

  (A_1 = 14.729, B_1 = -13.729, C_1 = 0.74, A_2= 0.011, B_2 = 1.2, C_2 = 0.548 for 2.8 MeV-cm^2/mg ^{20}Ne)
- θ is the incident angel of particles.

Failure probability in a word

$$P_{f1} \cong \sum_{i+j>L} \left[p_i \cdot p_j \cdot \left(1 - \frac{L}{N}\right) \right]$$ M. Zhu, 11

⇓

$$P_f = \sum_{i+j>L} \left(p_i \cdot p_j \right) \cdot \left(1 - \frac{L}{N}\right) \cdot \left(A_1 + B_1 \cdot e^{-\frac{t}{C_1}} \right)^2 \cdot \left(1 + \frac{\theta^\circ}{10^\circ} \cdot \left(A_2 + B_2 \cdot e^{-\frac{t}{C_2}} \right) \right)^2$$

- p_i and p_j are the probability of *i*-bit errors and *j*-bit errors produced by one event, respectively.
- L is the correction capability of ECC.
- N is the number of bits in a word.

MTTF

$$MTTF_{NBTI}\Big|_{MBU}^{nonscrubbing} = \frac{1}{\lambda'}\cdot\sqrt{\frac{\pi\cdot M}{2}} = \frac{1}{\lambda}\cdot\sqrt{\frac{\pi\cdot M'}{2}}$$

$$\cong \frac{1}{\lambda}\cdot\sqrt{\frac{\pi\cdot M}{2\cdot\sum\limits_{i+j>L}\left(p_i\cdot p_j\right)\cdot\left(1-\frac{L}{N}\right)}}\cdot\frac{1}{\left(A_1+B_1\cdot e^{-\frac{t}{C_1}}\right)\cdot\left(1+\frac{\theta^\circ}{10^\circ}\cdot\left(A_2+B_2\cdot e^{-\frac{t}{C_2}}\right)\right)}$$

$$MTTF_{NBTI}\Big|_{MBU}^{scrubbing} = t_s\cdot\frac{2\cdot M}{\left(\lambda'\cdot t_s\right)^2} = t_s\cdot\frac{2\cdot M'}{\left(\lambda\cdot t_s\right)^2}$$

$$\cong t_s\cdot\frac{2\cdot M}{\left(\lambda\cdot t_s\right)^2\cdot\sum\limits_{i+j>L}\left(p_i\cdot p_j\right)\cdot\left(1-\frac{L}{N}\right)}\cdot\frac{1}{\left(A_1+B_1\cdot e^{-\frac{t}{C_1}}\right)^2\cdot\left(1+\frac{\theta^\circ}{10^\circ}\cdot\left(A_2+B_2\cdot e^{-\frac{t}{C_2}}\right)\right)^2}$$

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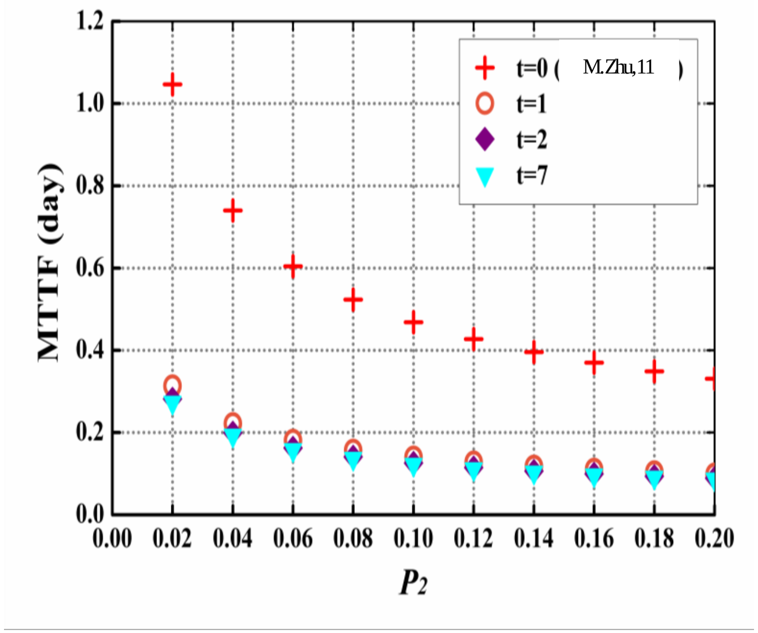
MTTF

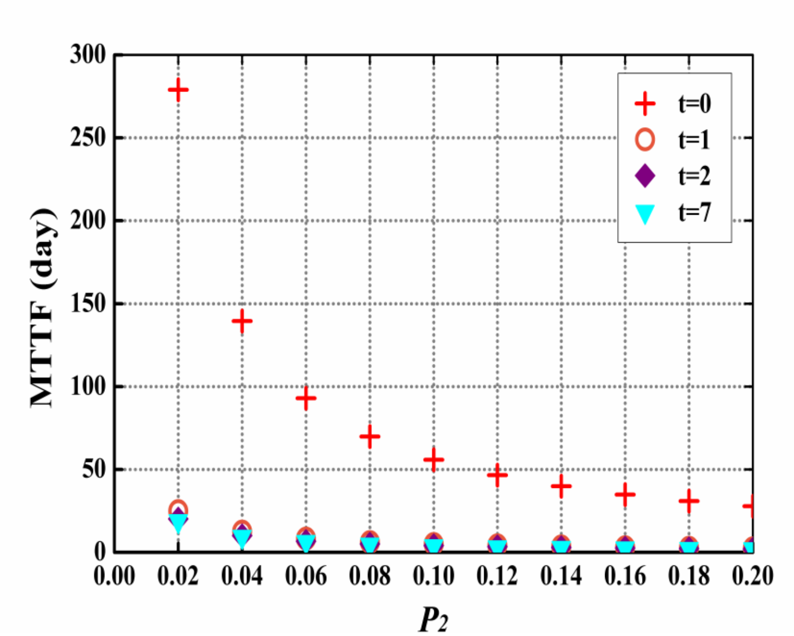
- The simulated radiation environment is established by Matlab;
- The memory size is that M=8K words with N=16 bits;
- The correction capability of ECC used is 2;
- The incident angles of particles are 0° , 45° , and 79° ;
- The errors that arrive at memory are assigned to Possion distribution;
- The heavy ion is ^{20}Ne (2.8 MeV-cm^2/mg) ;
- The scrubbing period t_s is 0.005.

MTTF

- The predicted MTTFs decrease over the NBTI stress time.



MTTF with different t for an M = 8 K, N = 16, L = 2 memory (nonscrubbing) when $\theta = 0°$



MTTF with different t for an M = 8 K, N = 16, L = 2 memory (scrubbing) when $\theta = 0°$

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Conclusion

- Through Geant4 simulation and parametric modeling, this paper proposed a MTTF model including NBTI stress time for 65 nm technology memories protected by ECCs against MBUs.
- The level of MTTF reduces by considering NBTI.
- Designers can evaluate a more accurate reliability for memories by using the proposed model during the early design.

THANK YOU！