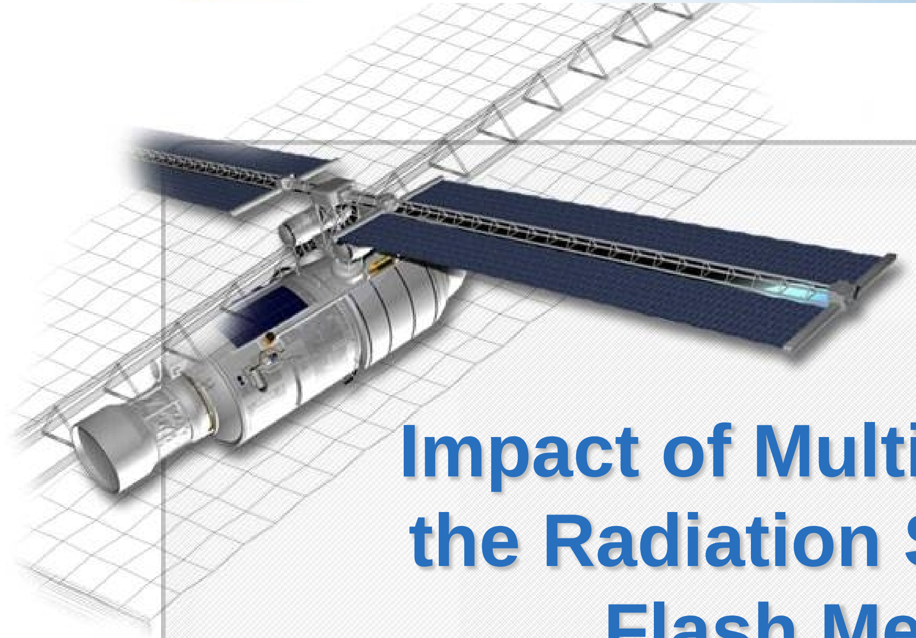

Impact of Multiple Write Cycles on the Radiation Sensitivity of NAND Flash Memory Devices

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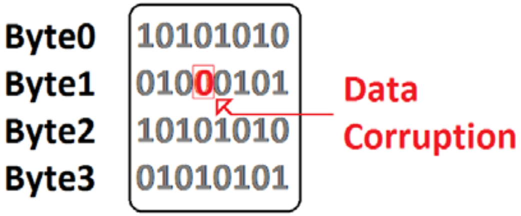
Introduction

- **Investigation about the impact of multiple write cycles on NAND Flash memory radiation sensitivity**
  - Successive pre-irradiation write cycles
  - Charge accumulation in floating gate

- **Application of the Flash memory hardening methodology proposed by M. Kay [4][5]**

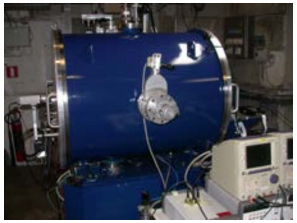
- **Main parameter studied : Data Corruption**
  - Data corruption = Relative percentage of corrupted data over all tested addresses
  - Comparison before/after irradiation



- **TID tests**
  - GAMRAY cobalt-60 facility (TRAD, Labege – France)
  - Evolution of the data corruption as a function of the TID level

GAMRAY facility – TID tests

- **Heavy ion tests**
  - Performed at UCL (Université Catholique de Louvain, Belgium)
  - Evolution of the SEU cross section as a function of the LET



UCL cyclotron
SEU tests

Tested devices

- **Two Flash memory commercial references from distinct manufacturers were tested**

Manufacturer	Micron	Samsung
Reference	MT29F128G08AJAAAWP	K9WBG08U1M-PCB0
Technology	SLC NAND Flash	SLC NAND Flash
Package	TSOP48	TSOP48
Size	128 Gb	32 Gb
Die number	4	2

- **Irradiated devices were initialized before irradiation**
  - **Store data by applying different numbers of write cycles in separated sectors of the memory array**
  - **Assessment of the write cycle number impact on the same die**

Pre-irradiation initialization

TID tests

Part type	Sector number	Sector size (256 kB blocks)	Number of write cycles
Samsung	1	100	1
	2	100	10
	3	100	100
	4	50	1 000
	5	10	5 000
	6	10	10 000
	7	10	100 000
Micron	1	100	1
	2	100	10
	3	100	100
	4	10	1 000
	5	10	10 000
	6	4	60 000

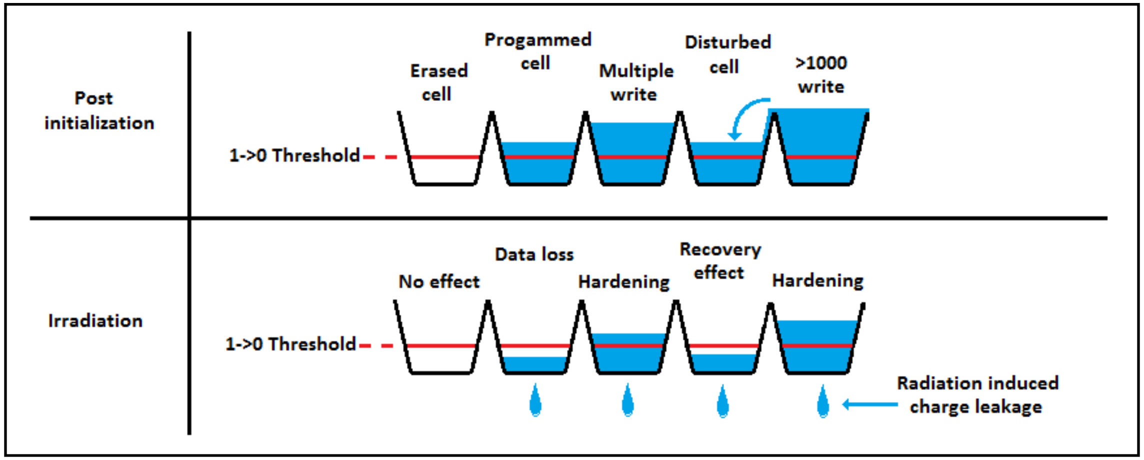
SEU tests

Part type	Sector number	Sector size (1 MB blocks)	Number of write cycles
Samsung	1	100	1
	2	100	10
	3	100	100
	4	50	1 000
	5	20	5 000
	6	20	10 000
	7	15	50 000
Micron	1	100	1
	2	100	10
	3	100	100
	4	50	1 000
	5	50	2 000
	6	10	5 000
	7	10	8 000

Disturbed cells and recovery effect

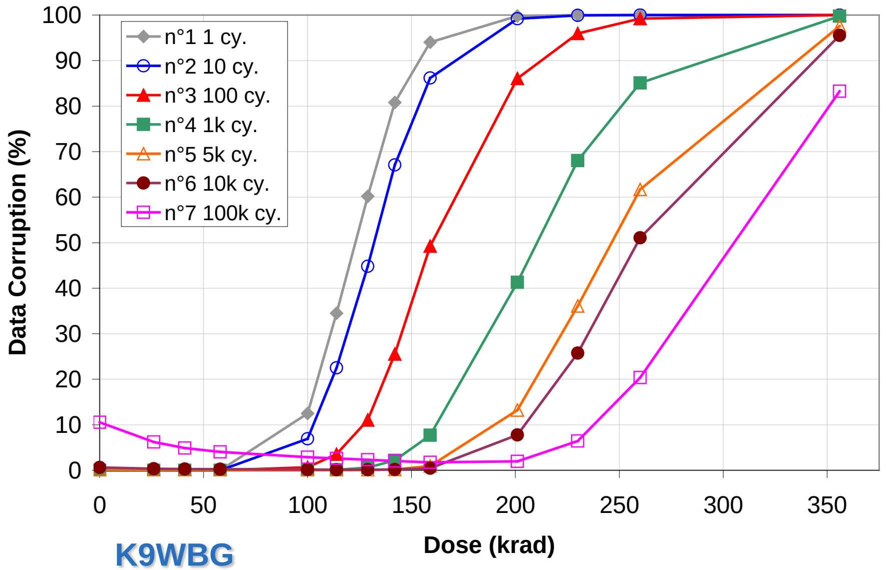
- **Initialization impact on the device functionality**
  - Generation of disturbed cells
  - Chekerboard pattern: accumulated charge leakage from « full » cells (0) to adjacent « empty » cells (1)

- **Radiation-induced recovery effect**
  - Radiation-induced charge leakage from disturbed cells
  - Expected data can be recovered

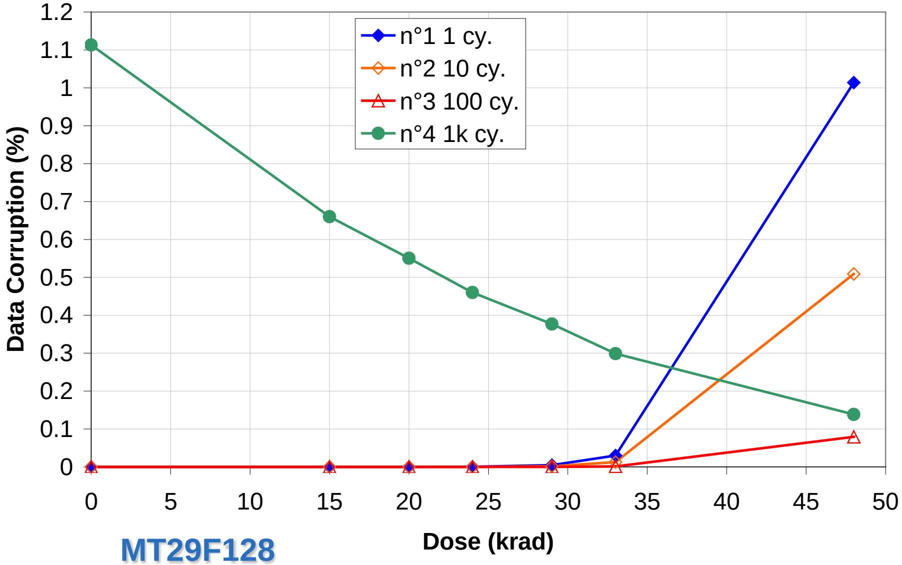


TID test results

- **Samsung K9WBG**
  - 10% of post-initialization distrubed cells before irradiation for 100 000 write cycles
  - Recovery effect observed
  - Trade-off between hardening effect and disturbed cell generation (around 1000 write cycles)
- **Micron MT29F128**
  - Same behaviour as the K9WBG but weaker TID hardness
  - Benefits of charge accumulation on TID-induced data corruption are visible above several tenth of krad
  - Importance of TID hardness to observe the benefits of multiple write cycles



K9WBG



MT29F128

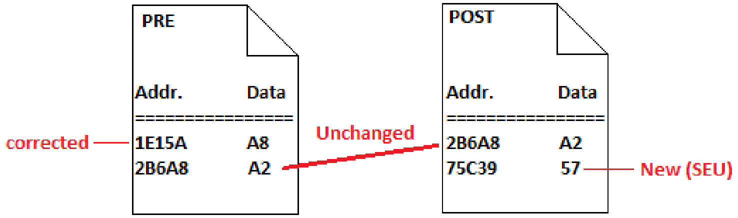
SEE test post-treatment

- **Due to the disturbed cell generation during pre-irradiation initialization, and the radiation-induced recovery effects, the SEU test data were post-analyzed in order to plot the SEU cross section**

- **During the SEU test**
  - **The memory content is just read before and after irradiation**

- **The recovery effect has to be taken into account**
  - **Make a distinction between the data corruption caused:**
    - By disturbed cells
    - By ion-induced SEU

- **Comparison between corrupted address/data before and after irradiation**
  - **Address with error <u>after, but not before</u>, is considered as modified by ion-induced SEU**
  - **Address with error <u>before, but not after</u>, is considered as modified by recovery effect**



PRE

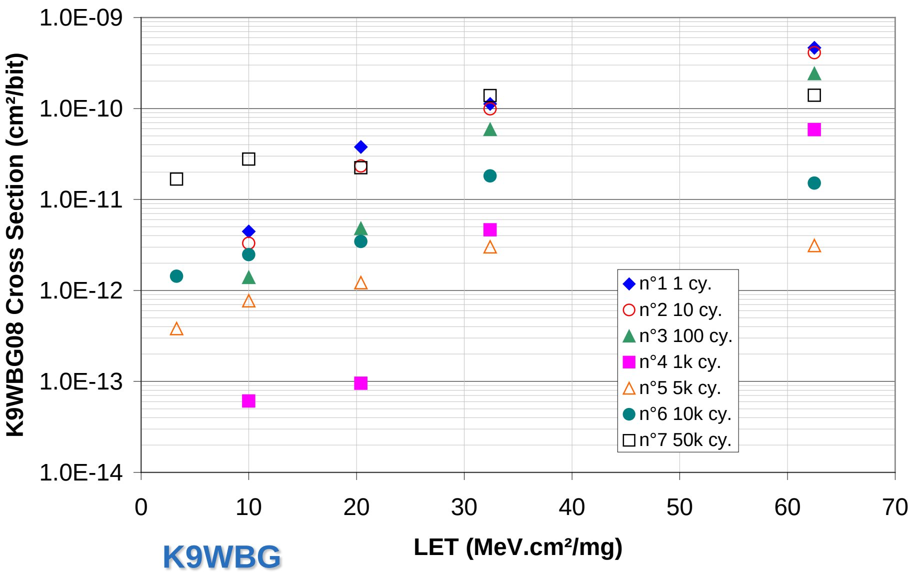
Addr.	Data
1E15A	A8
2B6A8	A2

POST

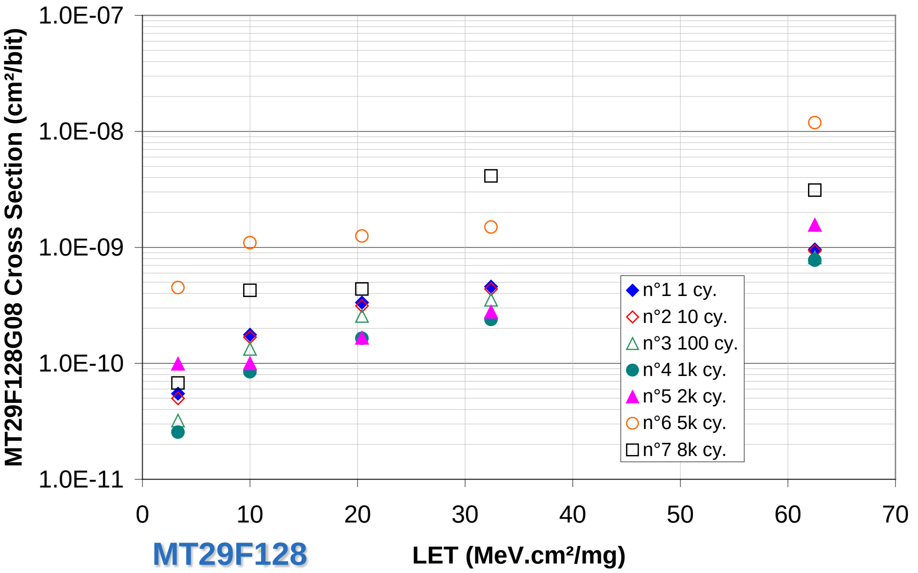
Addr.	Data
2B6A8	A2
75C39	57

SEU cross sections

- **For both references**
  - SEU cross section decrease up to 1000 write cycles
  - Above 1000 write cycles
    - SEU cross section increase
    - Lower SEU LET threshold (only for the Samsung K9WBG)



- **Limit of 1000 write cycles**
  - Below this limit the hardening effect due to charge accumulation can be significant, whereas the disturbed cell generation is low
  - Same limit observed for TID tests



Conclusion

- **Both tested references are sensitive to the charge accumulation caused by multiple write cycles**
  - Under TID the radiation-induced data corruption occurs at higher dose levels when the number of write cycles increases
  - SEU sensitivity can be decreased thanks to multiple write cycles
- **The application of a large number of write cycles generates disturbed cells**
  - Recovery effect observed under both TID and SEU tests
  - Trade-off between positive reduction of data corruption and generation of disturbed cells
- **On the tested references, 1000 write cycles is the best case**
  - Far below memory endurance
  - Small initialization-induced data corruption
  - Less radiation-induced data corruption
- **Interesting methodology for high dose application with radiation tolerant devices**
  - Hardening effect visible above several tenth of krad

References

[1] S. Gerardin et al. “Radiation Effects in Flash Memories” IEEE Trans. Nucl. Sci., vol. 60, no. 3, June 2013

[2] G. Cellere et al., “Direct evidence of secondary recoiled nuclei from high energy protons,” IEEE Trans. Nucl. Sci., vol. 55, no. 6, Dec. 2008

[3] Bagatin et al. “Increase in the heavy-ion upset cross section of floating gate cells previously exposed to TID” IEEE Trans. Nucl. Sci., vol. 57, no. 6, 2010

[4] M. Kay et al. “Effect of Accumulated Charge on the Total Ionizing Dose Response of a NAND Flash Memory” IEEE Trans. Nucl. Sci., vol. 59, no. 6, Dec. 2012

[5] M. Kay et al. “Using Charge Accumulation to Improve the Radiation Tolerance of Multi-Gb NAND Flash Memories” IEEE Trans. Nucl. Sci., vol. 60, no. 6, Dec. 2013