Flash Memory in Extreme Environments

Flash Memory Summit

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NSWC Crane

Flash Memory in DoD Applications

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Commercial

?

Defense

We've been researching issues associated with using commercial flash memories in extreme environments (like outer space).

Space Radiation Environment

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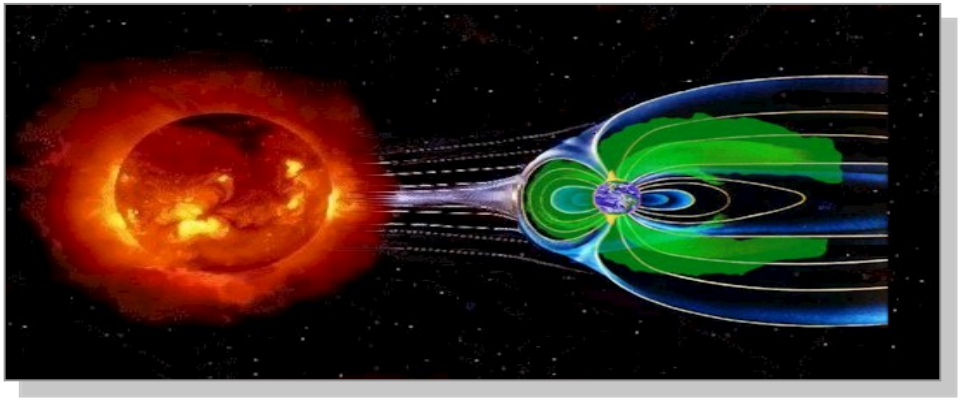
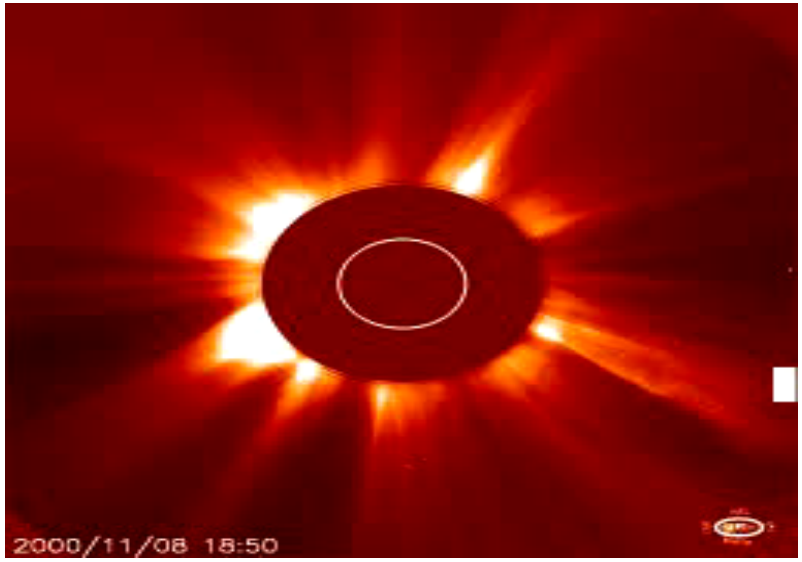


Image courtesy of NASA

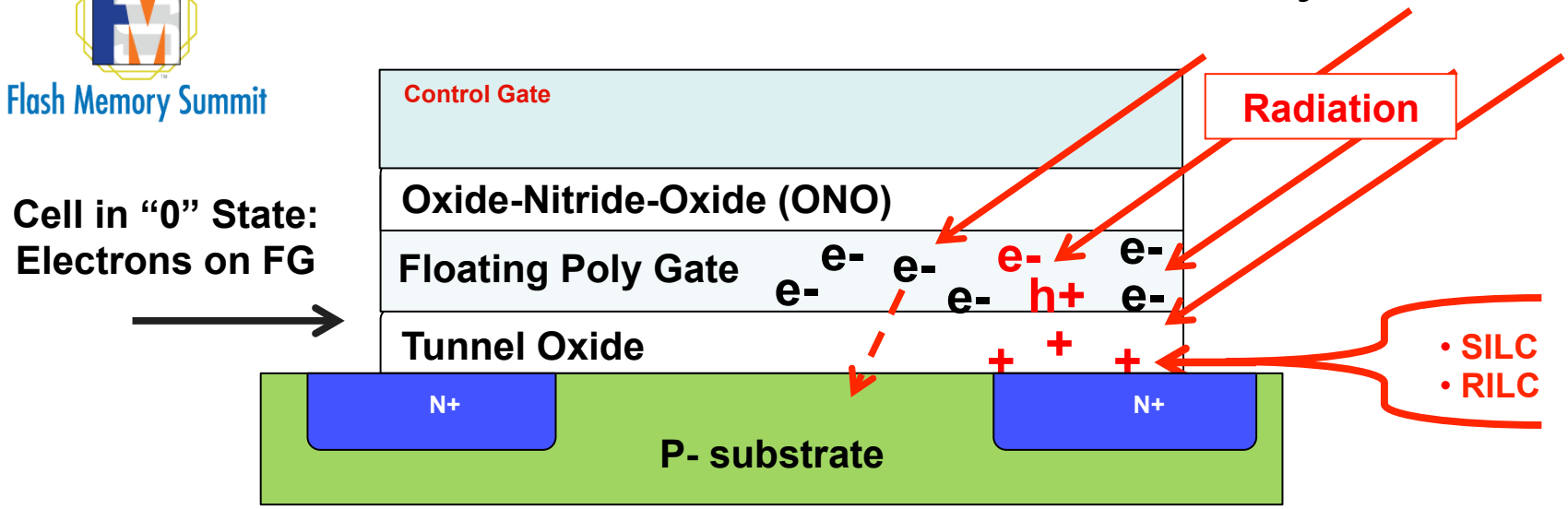
- Radiation from space can significantly degrade electronics
- Most radiation is deflected by Earth's magnetic field

Visual example of protons from a solar flare degrading an imager.



http://sohowww.nascom.nasa.gov/gallery/Movies/flares.html

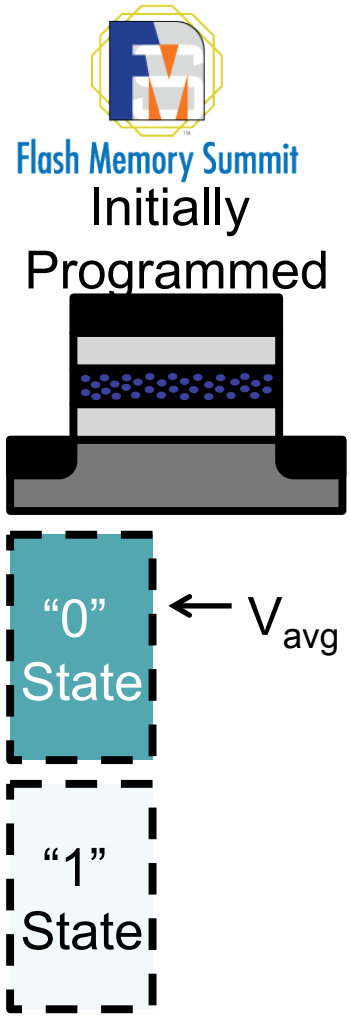
Radiation Effects in Flash Memory

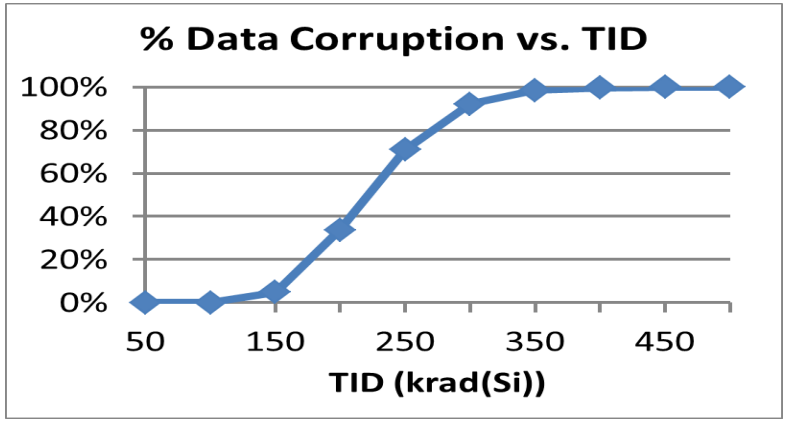


- **Physical mechanism of radiation-induced charge removal in NAND Flash is electron emission and electron-hole pair production and recombination.**

Radiation removes (or masks) electrons from the floating gate which causes bits to be in error.

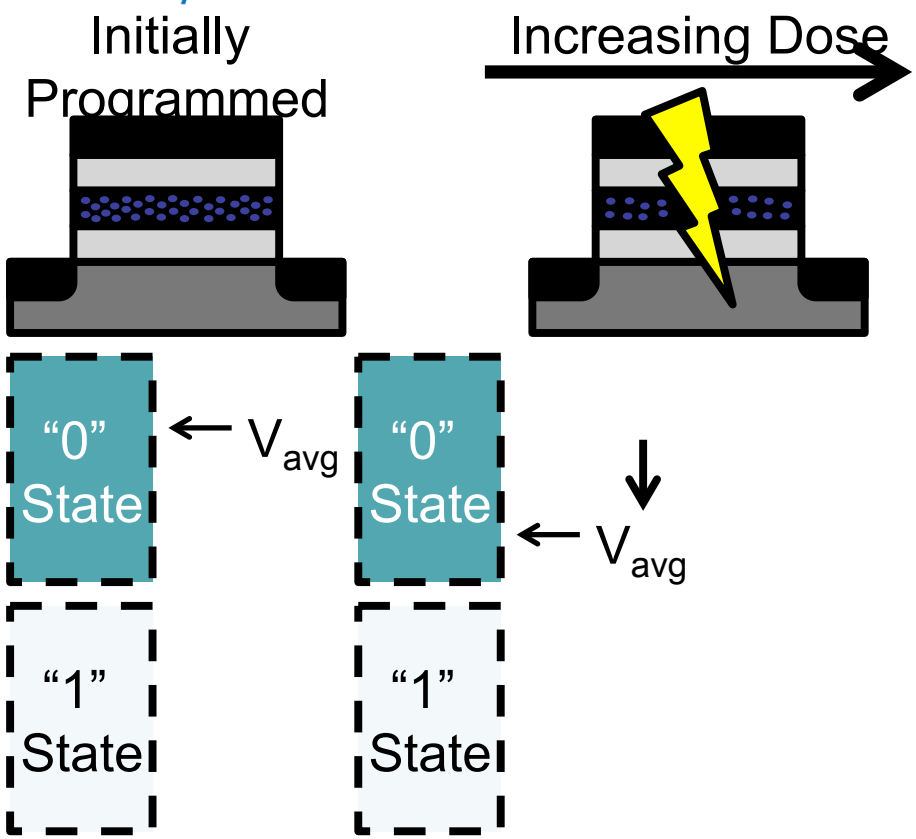
Effects of Radiation on Flash

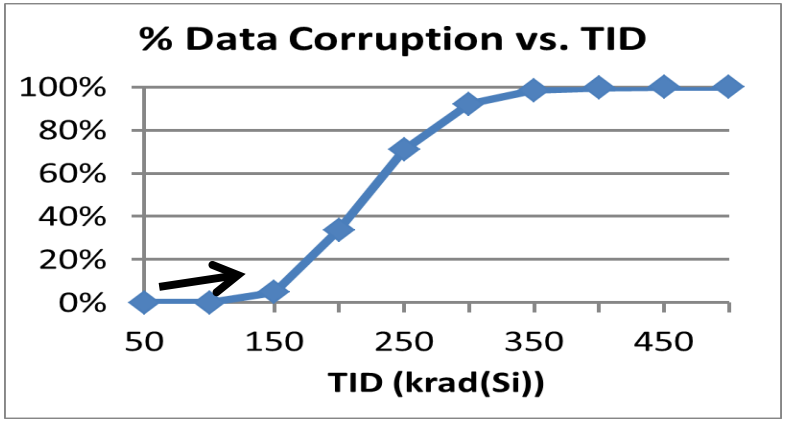




Charge is removed from floating gates with increasing total dose.

Effects of Radiation on Flash





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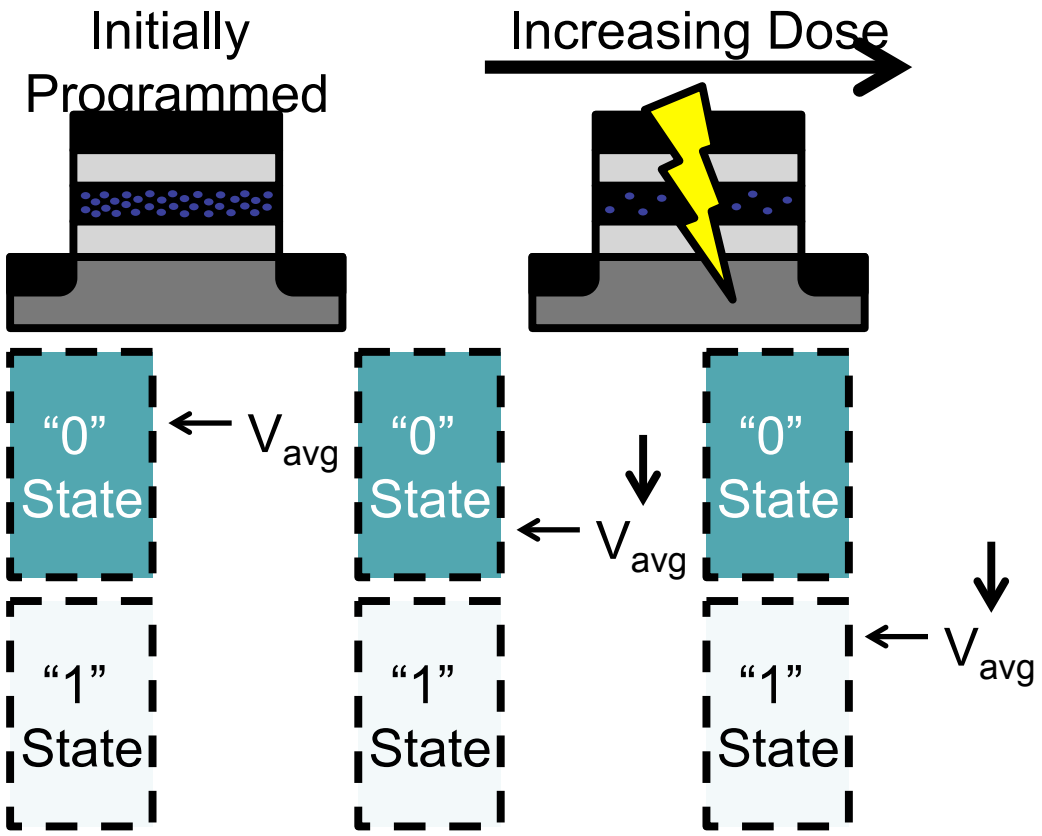
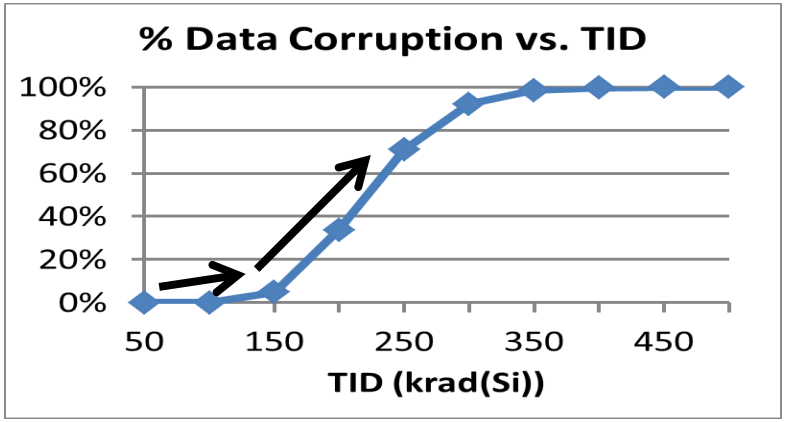
Effects of Radiation on Flash





Charge is removed from floating gates with increasing total dose.

Example Research Areas (in radiation effects)

1. **Techniques to improve the radiation tolerance**
2. **Advanced characterization methods**
3. **Floating-gate alternative non-volatile memories**

(1) Improving the Radiation Tolerance

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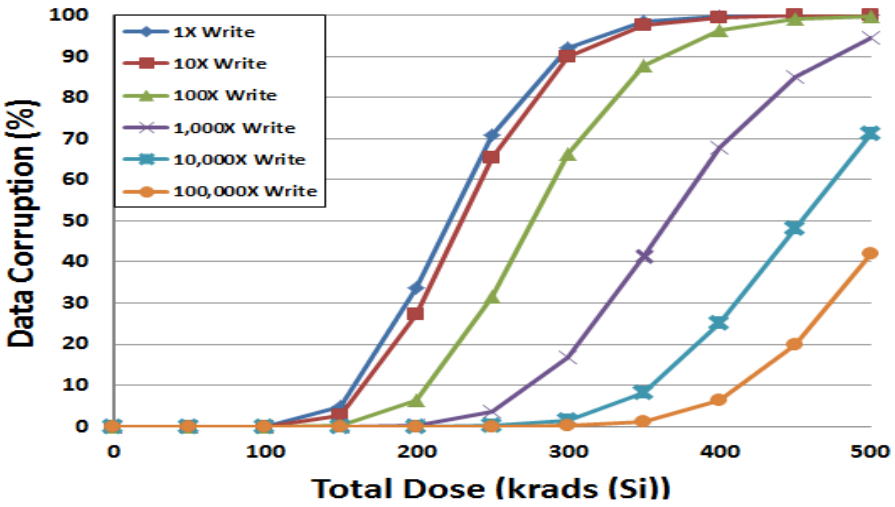
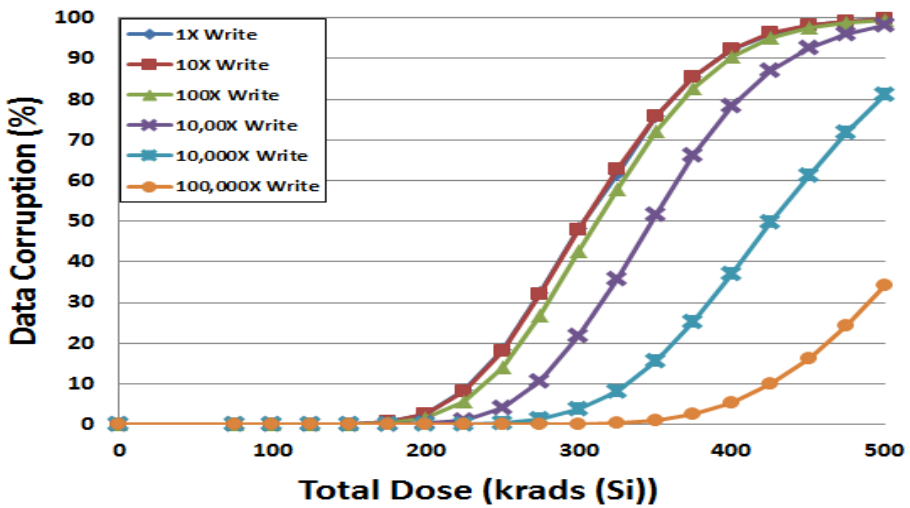
- **We've been able to show that by writing Samsung SLC flash memories multiple times more charge could be placed on the floating gate.**
- **This results in a larger amount of radiation needed to corrupt the data.**



Samsung 60-nm TID Results

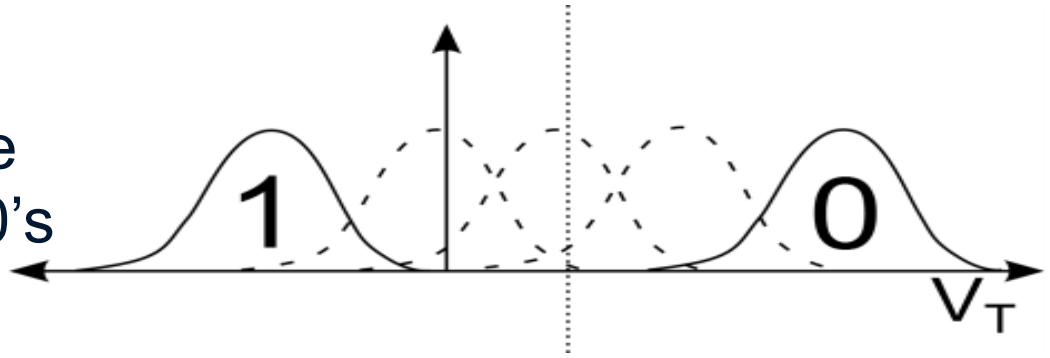


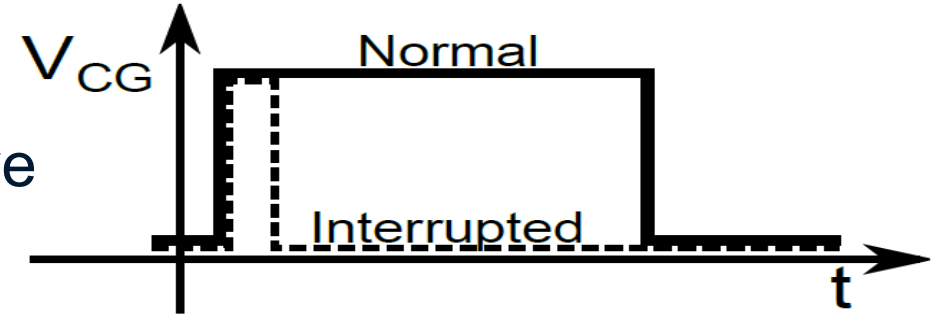
Samsung 42-nm TID Results

M. Kay, M. J. Gadlage, A. Duncan, J. D. Ingalls, and M. W. Savage, "Using Charge Accumulation to Improve the Radiation Tolerance of Multi-GB NAND Flash Memories," **published in the Dec. 2013 issue of the IEEE Trans. on Nuclear Science**

(2) Advanced Characterization of NAND Flash

- Want to be able to measure more than digital ‘1’s and ‘0’s from a COTS flash device
- Interrupted WRITE and ERASE commands incrementally add and remove charge from floating gate



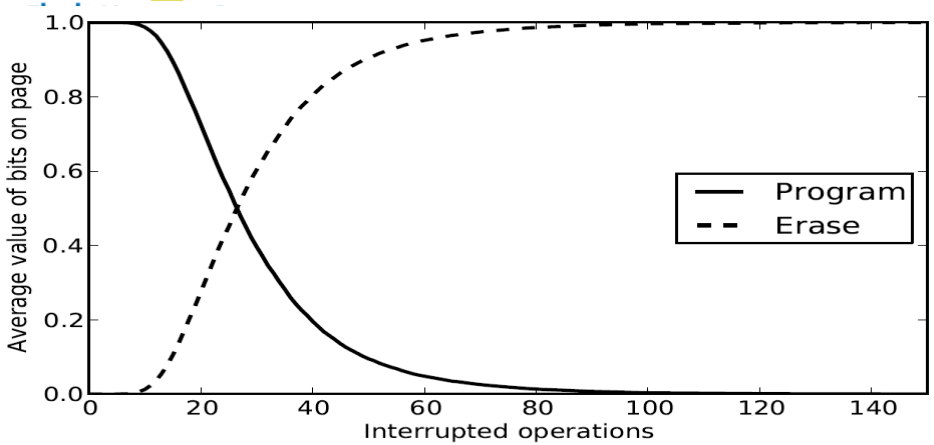


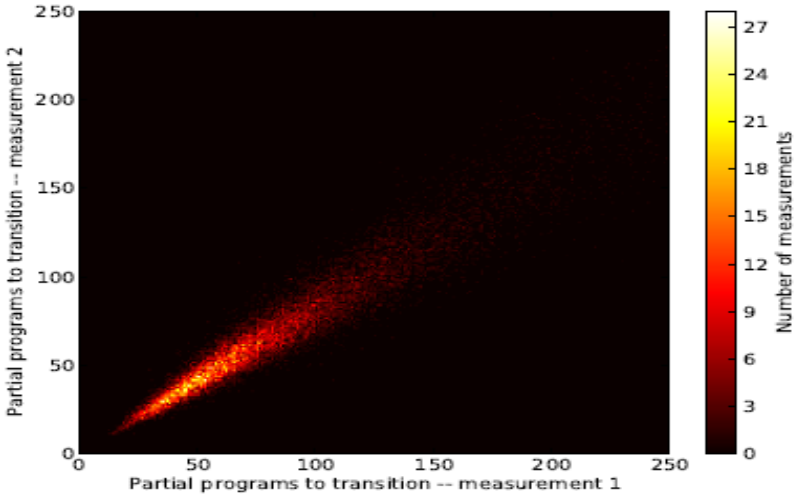
5.10 Reset

The device offers a reset feature, executed by writing FFh to the command register. When the device is in Busy state during random read, program or erase mode, the reset operation will abort these operations. The contents of memory cells being altered are no longer valid, as the data will be partially programmed or erased. The command register is cleared to wait for the next command, and the Status Register is cleared to value C0h when $\overline{WP}$ is high.

Samsung K9K datasheet

Interrupted operations in action

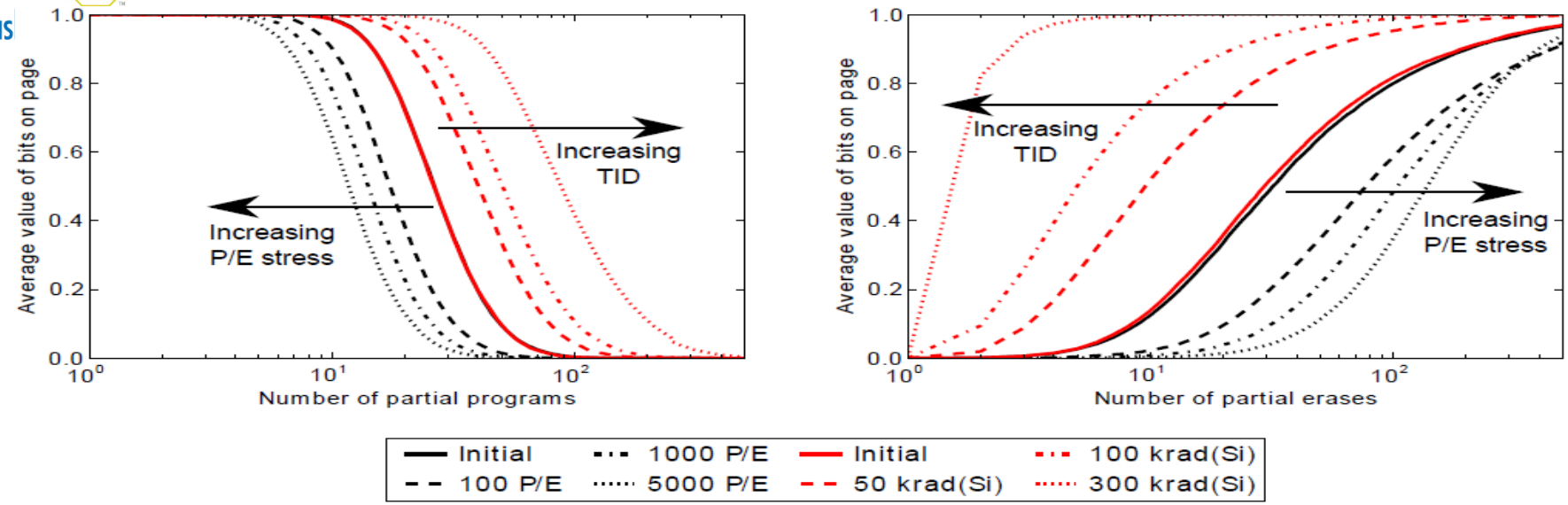




Required number of operations for each bit to transition is very repeatable.

This technique of partial programs/erases was first described by Cornell (Suh lab) for various security applications. We found that it works well for radiation effects & reliability analysis too.

Trapped charge in oxides



Technique allows measurement of trapped charge in oxides below threshold for bit cell failure.

"Interrupted PROGRAM and ERASE Operations for Characterizing Radiation Effects in Commercial NAND Flash Memories", published in the Dec. 2015 IEEE TNS.

(3) Floating-Gate Alternative NVMs

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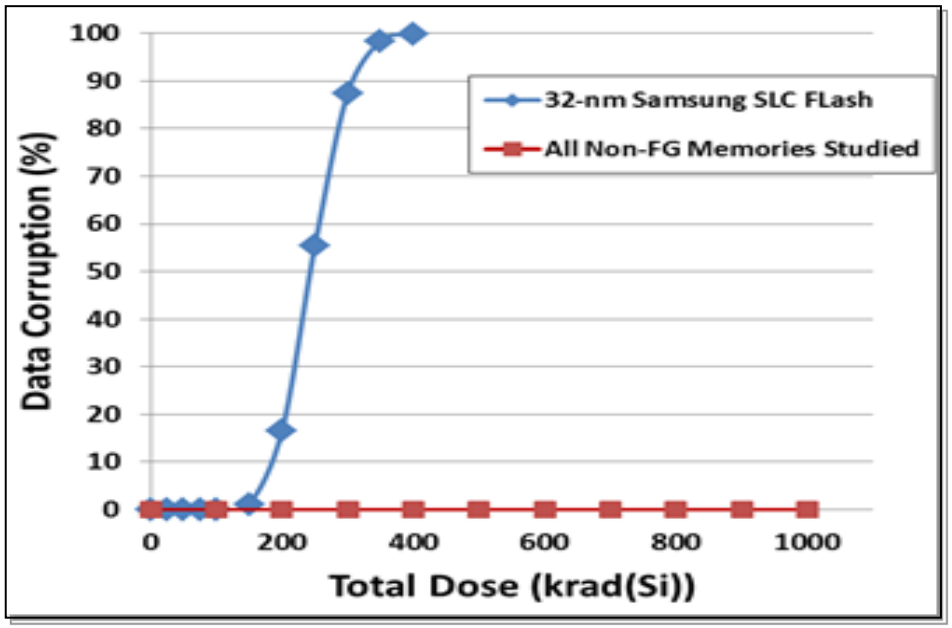
- The problem in a radiation environment with floating-gate memories is that data is lost to radiation even when the device is in an unpowered state.
- However, nearly all floating-gate alternative memories are inherently radiation tolerant.
- We've recently compared the radiation response of MRAM, FRAM, CBRAM, ReRAM, SONOS, and PCRAM devices to a relatively radiation tolerant NAND flash (published in the 2017 NSREC REDW).



No data corruption was observed on any of the FG-alternative memories studied when irradiated in an *unpowered* state.

Conclusions

- **When exposed to radiation, data is corrupted in floating-gate memories.**
- **We have a significant ongoing research effort that's focused on improving and understanding the radiation response of non-volatile memories in radiation environments.**
- **We are open to collaboration with NVM manufacturers!**

References (for further reading)

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3. J. D. Ingalls, M. J. Gadlage, A. R. Duncan, M. J. Kay, and P. Cole, "Implications of the Logical Decode on the Total Ionizing Dose Response of a Multi-Level Cell NAND Flash Memory," *Nuclear Science, IEEE Transactions on*, vol. 60, no. 6, pp. 4451-4456, Dec. 2013.
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5. M. Kay, M. J. Gadlage, A. Duncan, J. D. Ingalls, and M. W. Savage, "Using Charge Accumulation to Improve the Radiation Tolerance of Multi-GB NAND Flash Memories," *Nuclear Science, IEEE Transactions on*, vol. 60, no. 6, pp. 4214-4219, Dec. 2013.
6. A. H. Roach, M. J. Gadlage, A. R. Duncan, J. D. Ingalls, and M. J. Kay, "Interrupted PROGRAM and ERASE Operations for Characterizing Radiation Effects in Commercial NAND Flash Memories," *Nuclear Science, IEEE Transactions on*, vol. 62, no. 6, pp. 2390-2397, Dec. 2015.
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8. M. J. Gadlage, A. H. Roach, J. M. Labello, M. R. Halstead, M. J. Kay, A. R. Duncan, J. D. Ingalls, and J. P. Rogers, "Low-Energy Electron Irradiation of NAND Flash Memories," *Nuclear Science, IEEE Transactions on*, vol. 64, no. 1, pp. 212-217, Jan. 2017.
9. M. J. Gadlage, M. J. Kay, D. I. Bruce, A. H. Roach, A. R. Duncan, A. M. Williams, and J. D. Ingalls, "Total Ionizing Dose Effects in Commercial Floating-Gate-Alternative Non-Volatile Memories," published in the 2017 IEEE Nuclear and Space Radiation Effects Conference Data Workshop.